ASTRONOMY

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Voyager: On to Uranus

December's Dark Lunar Eclipse

How to Test Your Telescope's Optics

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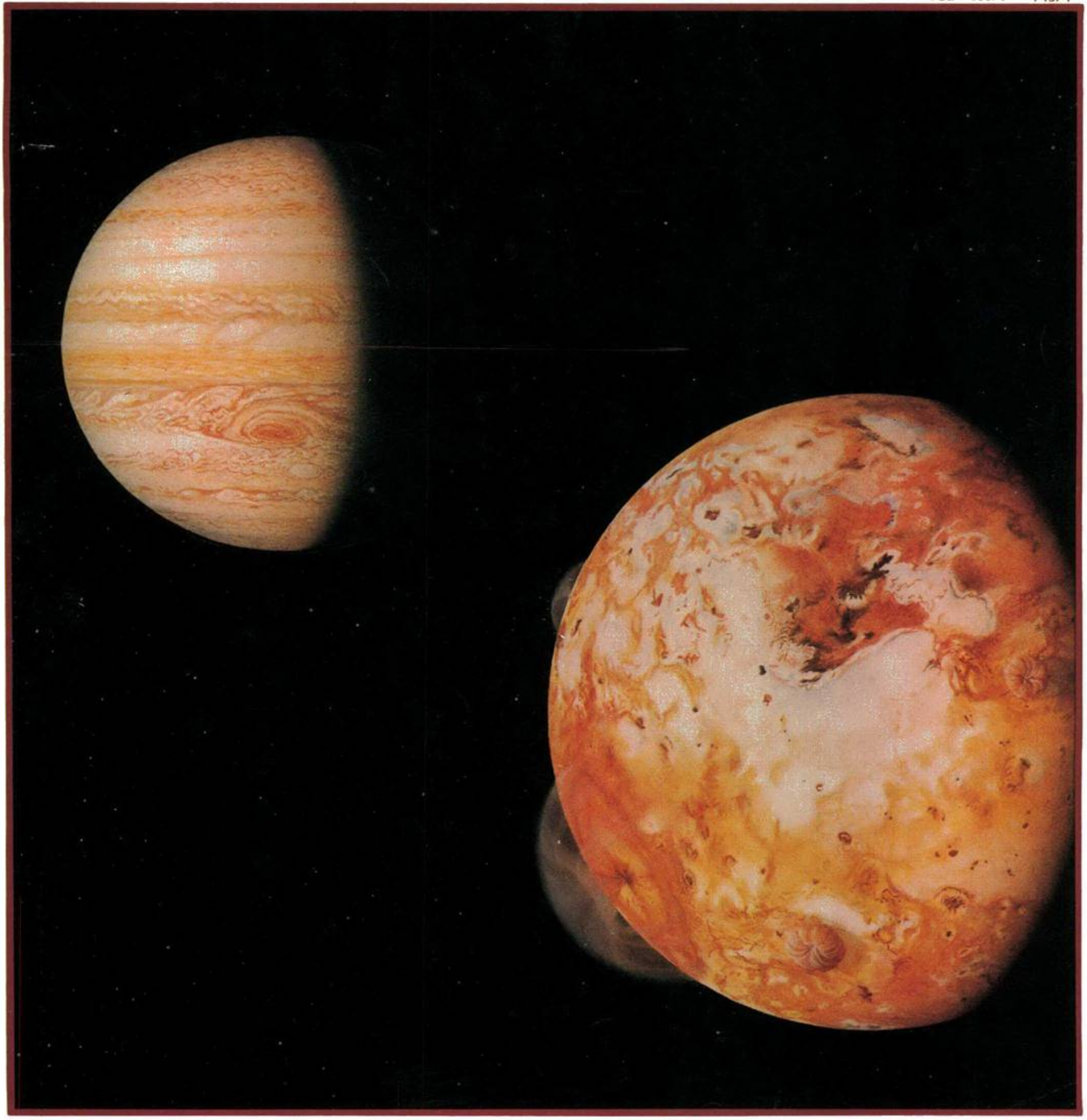

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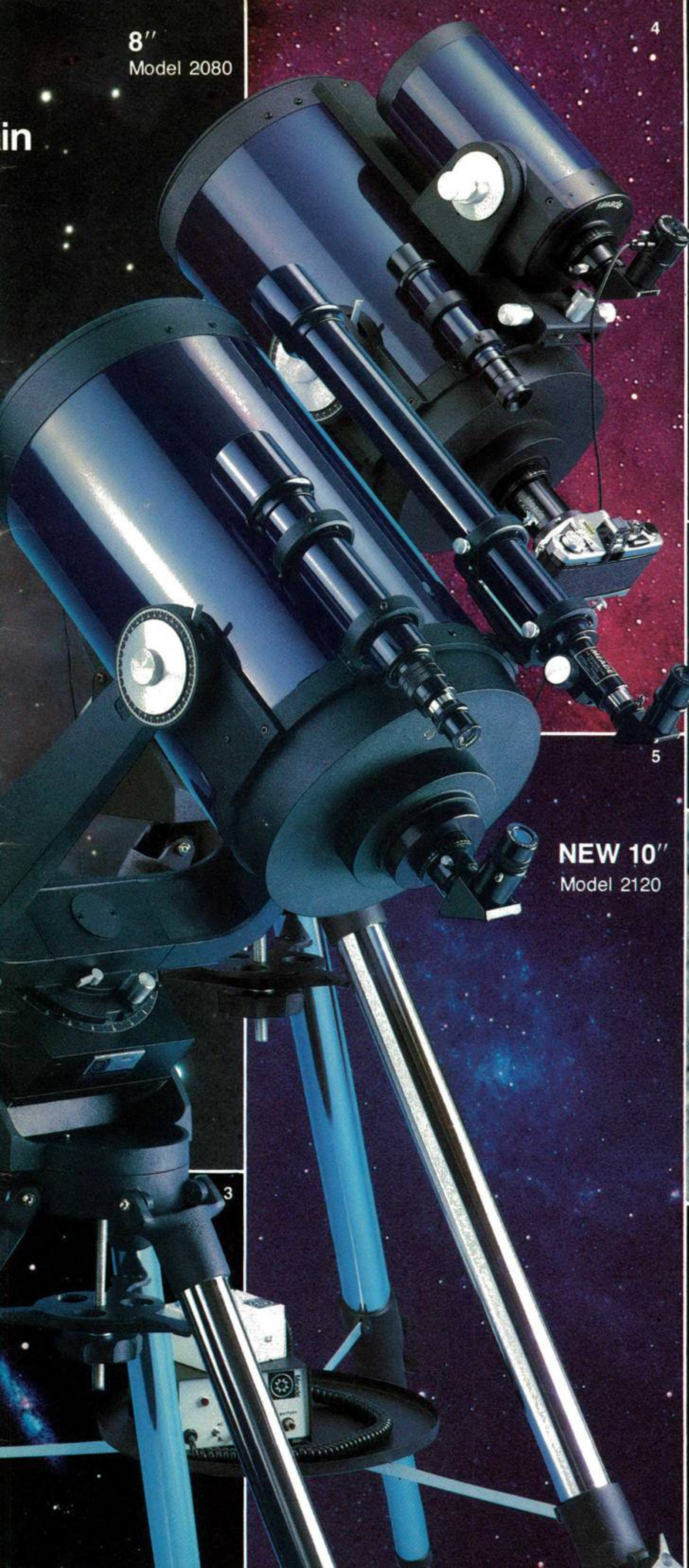
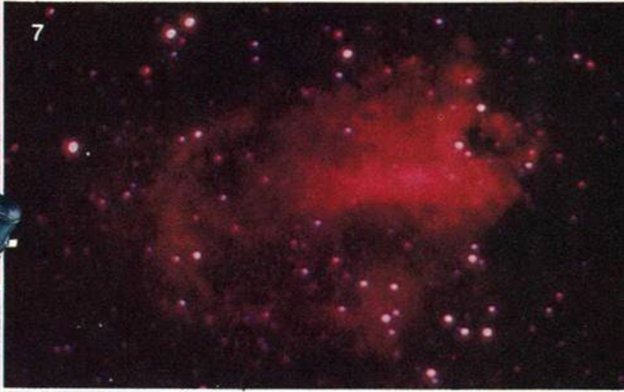
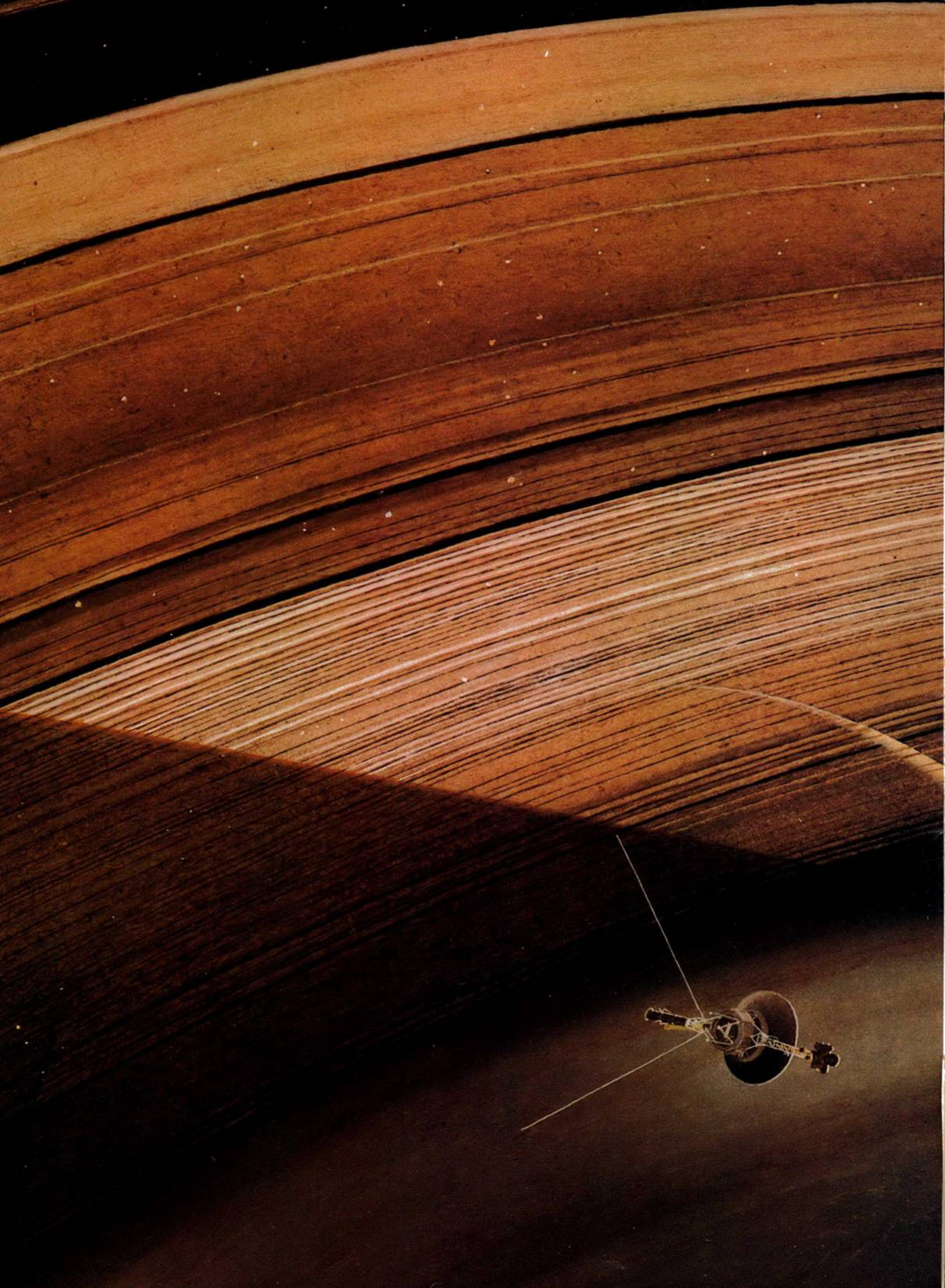


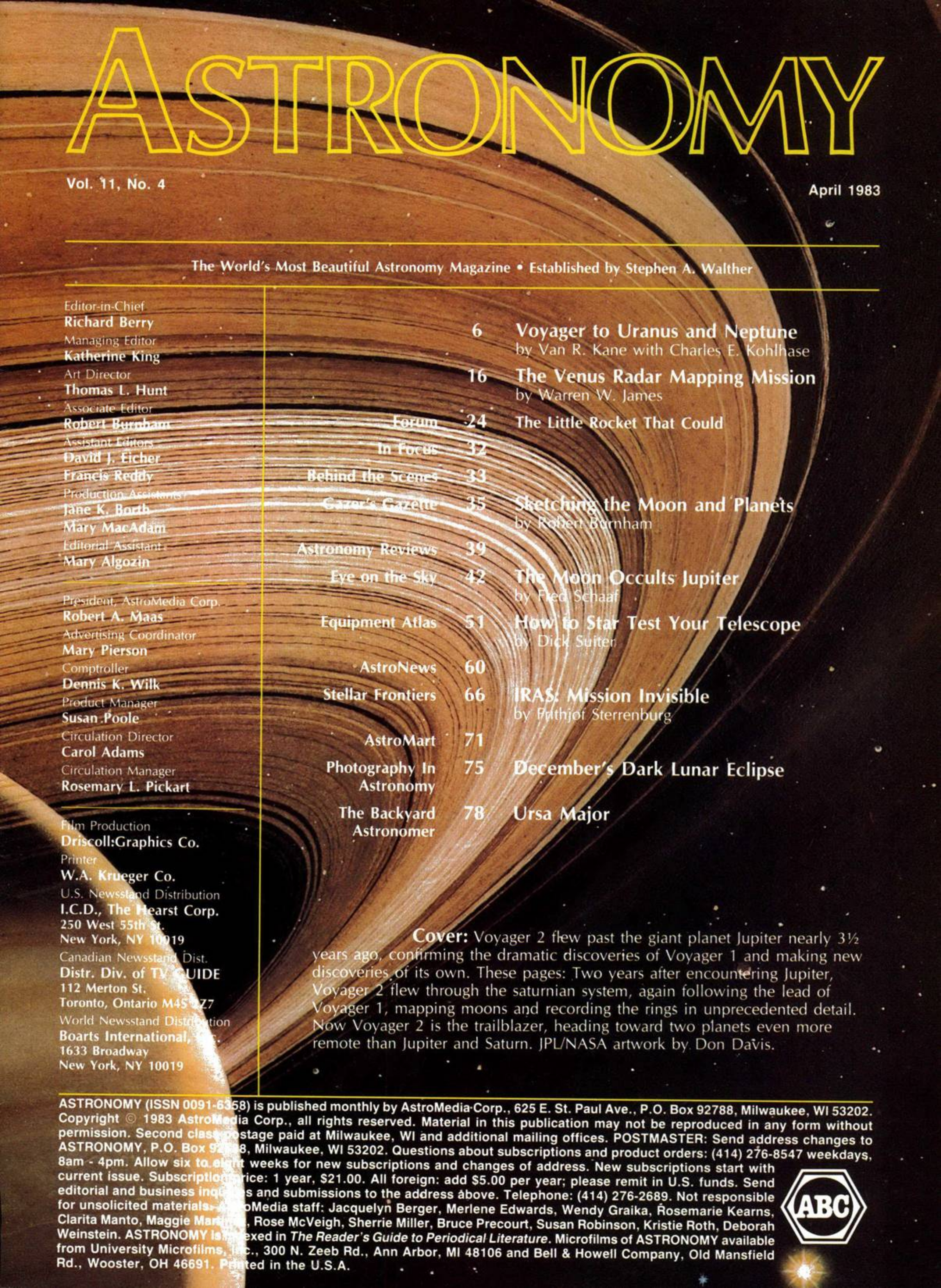


All astrophotographs shown on these pages were taken through off-the-shelf, unmodified Meade 8″ Model 2080 Schmidt-Cassegrain telescopes. For further technical details on these and many other astronomical photographs, send for your free copy of the Meade Schmidt-Cassegrain Astrophoto Brochure. (Alternately, the complete Meade 52-page General Catalog is available at $3.00 by First Class Mail and includes the Astrophoto Brochure at no additional charge.)

Key to Photographs
1, 2, 3, 5—Leo Henzl; **4, 7**—Emery Hildebrand; **6**—Paul Roques; **8**—John Sanford

1. Orion Nebula M42; exposure time 50 mins. **2.** Andromeda Galaxy M31; 60 mins. **3.** Galaxy M82; 60 mins. **4.** Milky Way in Sagittarius (50mm piggyback photo). **5.** Spiral Galaxy M33; 75 mins. **6.** Spiral Galaxy M51; 90 mins. **7.** Omega Nebula M17; 40 mins. **8.** Moon—Clavius region.





ASTRONOMY

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Cover: Voyager 2 flew past the giant planet Jupiter nearly 3½ years ago, confirming the dramatic discoveries of Voyager 1 and making new discoveries of its own. These pages: Two years after encountering Jupiter, Voyager 2 flew through the saturnian system, again following the lead of Voyager 1, mapping moons and recording the rings in unprecedented detail. Now Voyager 2 is the trailblazer, heading toward two planets even more remote than Jupiter and Saturn. JPL/NASA artwork by Don Davis.

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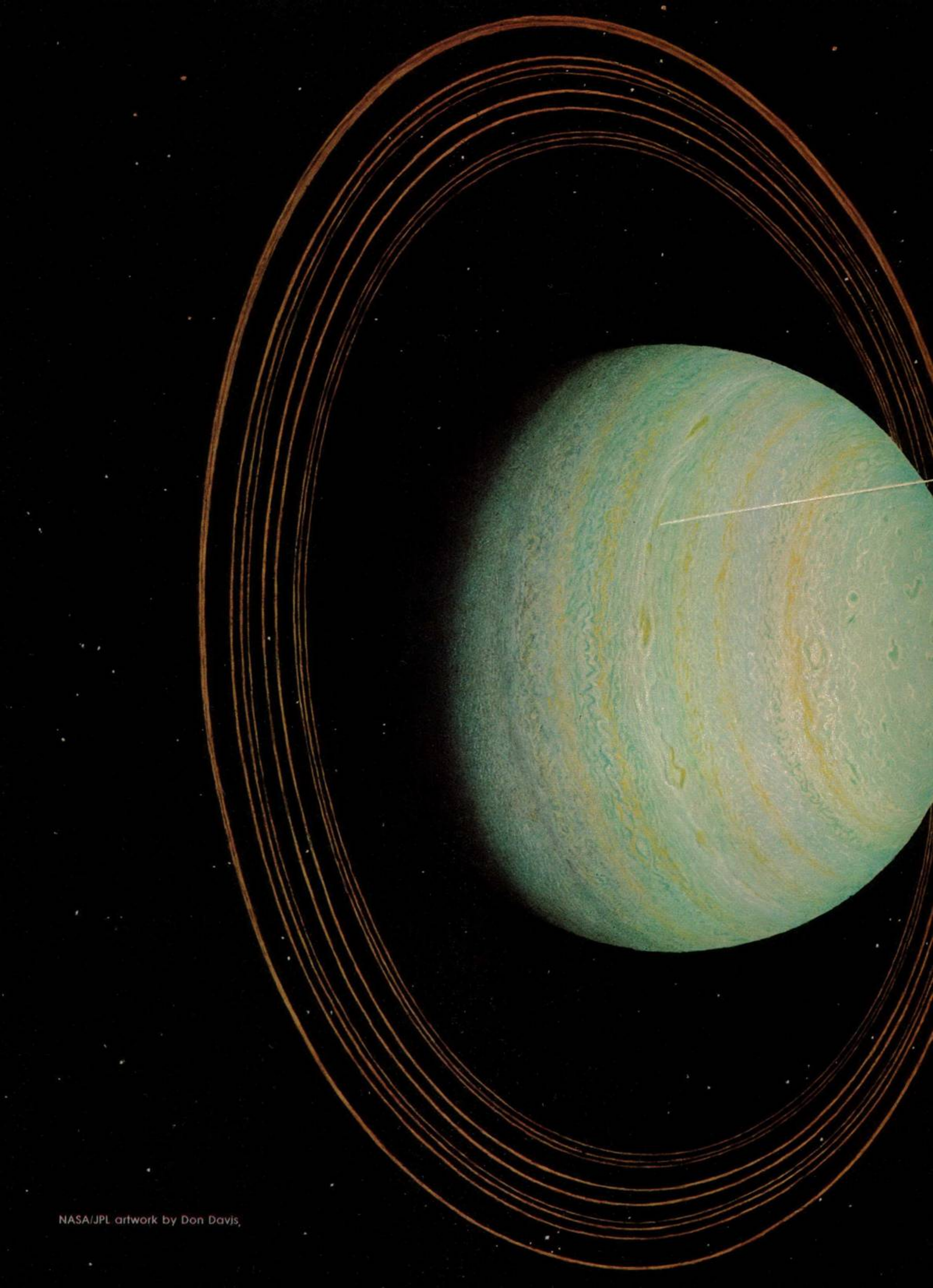
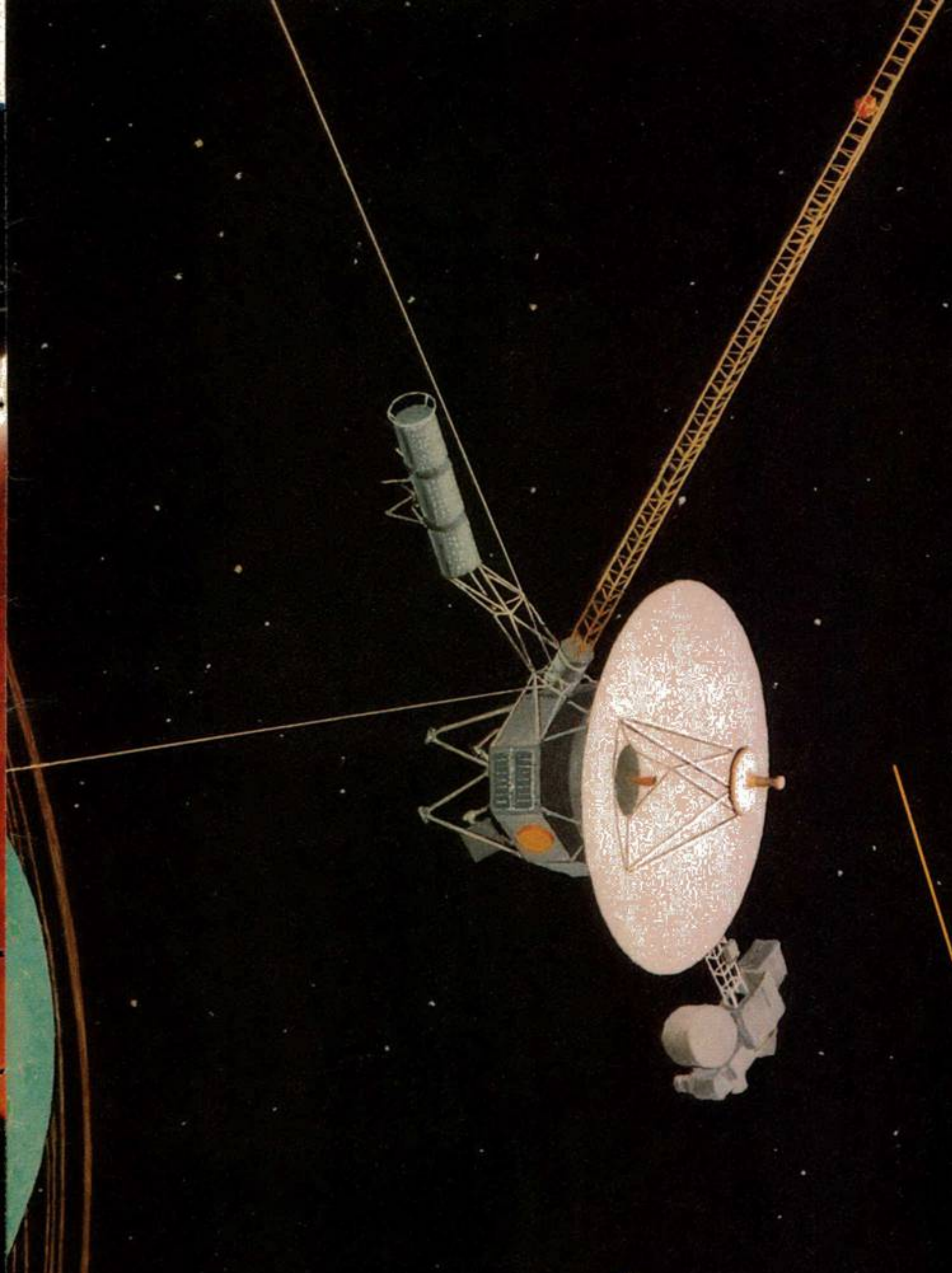


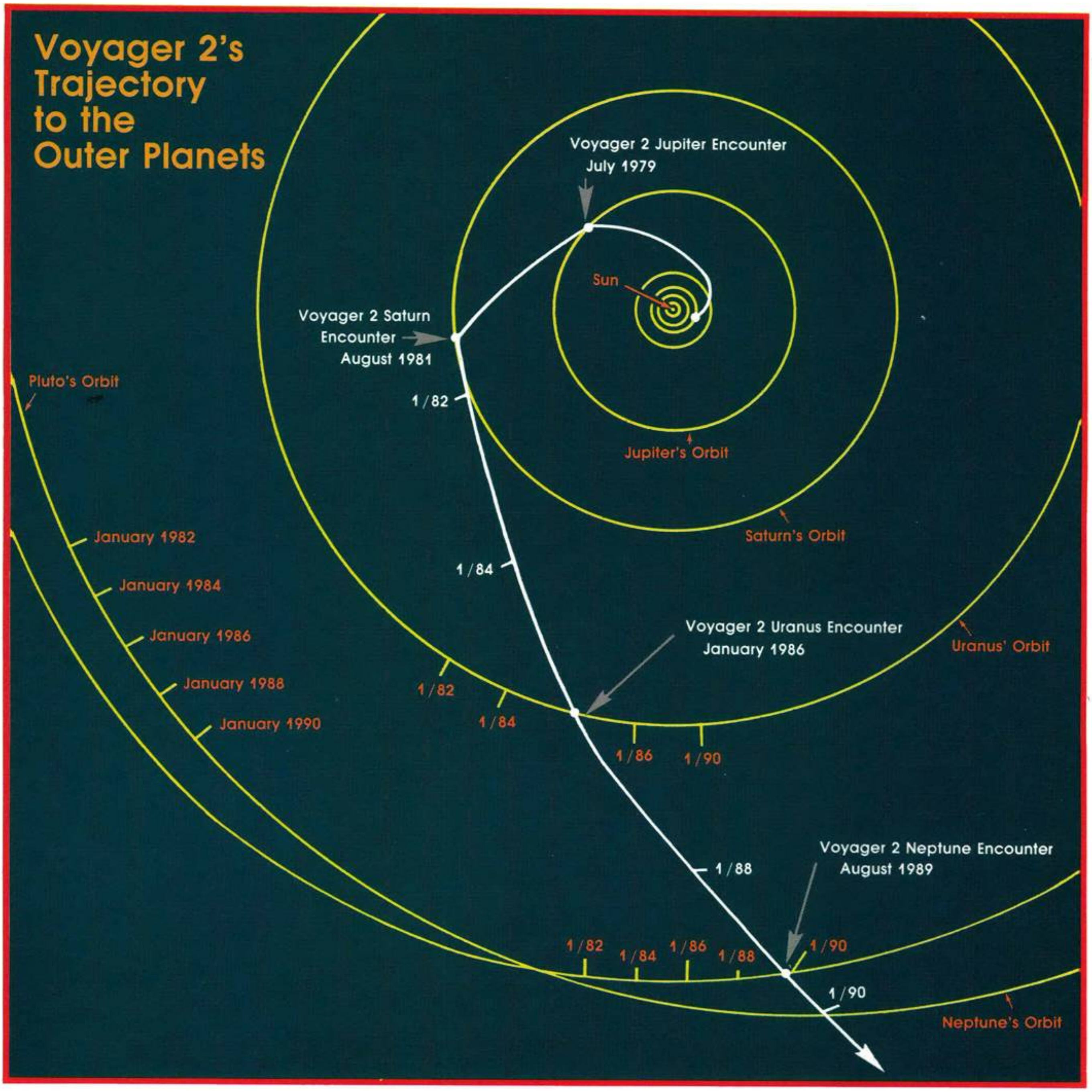
NASA/JPL artwork by Don Davis



VOYAGER to Uranus and Neptune

by Van R. Kane
with Charles E. Kohlhase

It fell to a graduate student in aeronautics, doing pre-doctoral studies at the Jet Propulsion Laboratory, to discover the way to the outer planets. As he casually called it in the abstract of his 1966 paper, the Grand Tour is the name of the solution he found. Gary Flandro, now at the University of Utah, had been wrestling with the fundamental problem in exploring the outer planets: time. For all their apparent power, rockets are puny things on


Voyager 2's Trajectory to the Outer Planets
Voyager 2 Jupiter Encounter July 1979
Sun
Voyager 2 Saturn Encounter August 1981
Pluto's Orbit
1/82
Jupiter's Orbit
Saturn's Orbit
January 1982
January 1984
January 1986
January 1988
January 1990
1/84
Voyager 2 Uranus Encounter January 1986
Uranus' Orbit
1/82
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Voyager 2 Neptune Encounter August 1989
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Neptune's Orbit

the scale of the solar system. A flight to Jupiter would take two years, an acceptable journey for a robot explorer. But a flight to six-times-more-distant Neptune would take 40 years — too long for either human or robot.

However, Flandro had been intrigued by some calculations made by Michael Minovich, another analyst at JPL, which suggested that Jupiter's gravity could be used to shorten voyages to the outer worlds. Decades before, astronomers had learned that the giant planet's gravitational field can alter the velocity and direction of a passing comet, either condemning it to tight orbits around the Sun or flinging it out of the solar system entirely.

Of the opportunities Flandro found for spacecraft to play comet, one stood out. A rare alignment of the outer planets meant that a craft could use Jupiter to go on to Saturn, then to Uranus, and finally to Neptune in a flight lasting 12 years. The last opportunity for Grand Tour had occurred when Thomas Jefferson was president. The next opportunity would come in 1977.

Today, Voyager 2 very nearly follows the path discovered by Flandro. The encounters with Jupiter and Saturn are history. Uranus and Neptune lie years ahead. The mission has survived budget cuts, equipment failures, aging parts, and limited propellant reserves. Stubbornness and good fortune are making the Grand Tour possible — with its promise of discovery.

Distance obscures Uranus and Neptune. Even the closer of the two remained undiscovered until just seven months before the Battle of Yorktown effectively ended the American Revolution. In 1781, William Herschel, an organist, telescope maker, and astronomer in Bath, England, spotted a blue-green dot while looking for double star systems in the constellation Gemini. A few months of observation convinced him that he'd discovered not a comet, as he'd first thought, but a seventh planet. He named the new world *Georgium Sidus — "The Georgian Planet"* — in honor of the same king the American colonists had rebelled against. (The flattery didn't hurt: Herschel became *Sir* William Herschel as well as the father of stellar astronomy.) Joseph Lalande suggested an alternate name, *Herschel*. Johannes Bode suggested the name that stuck — *Uranus* — but it was sixty years before the mythical name won out.

About that time, in the late 1840s, an Englishman and a Frenchman were using irregularities in Uranus's orbit to predict the location of an eighth world. Both passed their calculations on to the leading astronomers in their respective countries, none of whom cared to look for the planet. Thus it was two Germans who discovered Neptune on September 23, 1846 — the same day they received a copy of the Frenchman's predictions.

But knowledge of these new outer worlds accumulated slowly. Observers learned that, like Jupiter and Saturn, these worlds are gas giants with thick atmospheres. But while Jupiter and Saturn are true giants that missed becoming stars, Uranus and Neptune are comparatively small planets, about a third Jupiter's diameter and a twentieth its mass. It's not that they are tiny — each is almost as much larger than Earth as Earth is larger than the Moon — but that Jupiter is so big. Uranus and Neptune are "mid-size" planets.

Astronomers learned that more than just size and mass sets the two pairs of jumbo planets apart. Jupiter and Saturn are reduced copies of the Sun; some 97% of their bulk is composed of hydrogen and helium. A spicing of other gases, rocks, and metals completes the recipe. Uranus and Neptune, on the other hand, divide their bulk evenly among three layers: hydrogen-helium atmospheres, methane-ammonia-water mantles, and rock-metal cores.

Other facts came to light from time to time. The discoveries of their seven known moons came in spurts over 163 years. The last confirmed discovery came in 1950 with the sighting of Neptune's second moon, tiny Nereid. (A possible third neptunian satellite now awaits confirmation.) Unlike other planets, including Neptune, which stand more or less upright, Uranus lies on its side; its rotational axis tilts some 98° to the plane of its orbit.

Neptune apparently produces more heat inside itself than it receives from the Sun, while Uranus apparently does not. On the other hand, Uranus has a family of rings about it, while Neptune apparently does not. (Some rain-soaked computer cards recording a 1968 stellar occultation suggest that Neptune may also have some rings, but because several deliberate searches since then haven't turned them up, many astronomers doubt their existence.)

Even today, though, we know less about these worlds than we knew about Mars when the first spacecraft examined it. The best photographs of them show almost no details. Even basic information such as their exact size and the length of their days remains in doubt. Flandro's discovery — a chance to explore Uranus and Neptune by spacecraft — was too good to pass up.

In the waning years of the 1960s, only one spacecraft, Mariner 4, had reached Mars. Armstrong and Aldrin had yet to walk on the Moon. Thinking about building craft for 12-year flights to the edge of the solar system could only be described as very ambitious.

New technologies would have to be invented. Because the spacecraft would be too far from the Sun to use solar power, miniature nuclear generators would power the spacecraft's scientific instruments and radio. On-board computers would have to handle emergencies on their own because any message reporting problems to humans would take hours to reach Earth. Even the scientific instruments would have to be new designs because the existing ones weren't designed to function for 12 years. In short, the Grand Tour spacecraft were exactly the kind of challenge JPL's engineers love. They went to work.

By December 1971, when the mission was canceled, most of the technical problems had been solved. The mission planners had sweetened the itinerary by adding Pluto. Richard Nixon had personally endorsed the project. Yet federal parsimony, the need to fund the Space Shuttle out of a shrunken space budget, lingering doubts about the spacecraft's lifetime, and the nearly $1 billion cost killed the Grand Tour.

Congress stepped in the following summer with a $360 million authorization for a less ambitious Mariner Jupiter-Saturn project, later to be renamed Voyager. The new MJS mission would merge the Grand Tour technologies with the tried-and-true technologies of craft that already had flown to Venus and Mars. In their basic design and abilities, the Voyagers would resemble the Grand Tour craft. The critical difference between them would lie in their expected lifetimes. Each Voyager would be built for the 4-year flight to Jupiter and Saturn, not the 12-year flight to Neptune.

It didn't take planetary scientists long to reconcile themselves to the Grand Tour's death. Jupiter and Saturn, the giant planets, had been the highlights of that trip anyway. And the space agency planned to send a third identical craft on a Jupiter-Uranus mission just two years after the first two craft left Earth.

But NASA learned in 1975 that it wouldn't get the money to launch the third Voyager. Even so, Uranus remained a priority because it is so different from the giant planets already on the itinerary. The mission planning office dusted off the old Grand Tour plans to look at their options. Celestial mechanics said that one or both craft could continue from Saturn to Uranus and even to Neptune. The mission's science goals, however, posed a problem.

After Jupiter and Saturn themselves, their respective moons Io and Titan had top priority for study. Any spacecraft passing close to Io would also pass close to Jupiter, gaining, in the process, so much speed it would arrive at Saturn too early for that planet's gravity to redirect the spacecraft to Uranus. Furthermore, any spacecraft passing close to Titan would also forgo Uranus because it would leave Saturn headed in the wrong direction. The project's scientists weren't willing to give up either moon for a chance that an aging spacecraft might survive to reach another world.

So NASA arranged to have its cake and eat it, too. Voyager 1 would fly past *both* moons, giving up its chance for the Grand Tour but fulfilling the scientific goals for Jupiter and Saturn. Voyager 2, following behind, would be held ready to replace the first craft if it failed to return good data from Titan — but ready to go on to Uranus if Voyager 1 was successful. NASA's management wouldn't have to decide whether to target the second craft for Uranus or not until after Voyager 1's Saturn encounter.

When the two spacecraft left Earth in August and September of 1977, the project managers were calling the Grand Tour a long shot. Despite problems from time to time, both craft more than fulfilled their goals. On August 25, 1981, Voyager 2 cleared Saturn, headed for Uranus: the Grand Tour was on.

Still, it's not a sure thing. While formulas exist to calculate the probability of successfully reaching and studying the two remaining worlds, the results are based on data that sometimes are just best estimates or best guesses. The Voyager planning office at JPL uses both calculations and their gut feelings to estimate the chances of finishing the flight. The Voyager 2 spacecraft, they estimate, has a 70% chance of a successful flyby at Uranus and just under a 50% chance at Neptune. The estimate depends on two factors: the health of Voyager's equipment and the propellant supply.

So far, most of the hardware problems have been minor, but age is taking its toll. A complex problem involving lubricant migration and thermal expansion causes the scan platform (which points the cameras and several other instruments) to stick when it moves about the azimuth axis. Then there's design lifetime: the narrow angle camera, for example, must be turned off for most of the flight between planets, although it has ample life expectancy for being on during the Uranus and Neptune encounters. An integrated chip has failed, reducing the memory capacity in one of the twin scientific computers by 3%. (A similar chip failure aboard Voyager 1 affects a much larger portion of its memory.) And the craft's X-band transmitters, which send data back at a higher rate than the S-band transmitters, must be left on for the rest of the flight, because they might not survive being switched on and off repeatedly.

An ailing radio receiver provides somewhat more worry. A few months after launch, a power surge aboard Voyager 2 knocked out the primary receiver and damaged its backup. The surviving unit has so far successfully received messages sent from Earth — some five years of operation. Just in case, mission controllers have stored instructions on board Voyager telling it how to reach and study Uranus should it never hear from home again. Instructions for the Neptune encounter can't be sent until after trajectory modifications have been made following the Uranus flyby. Should the receiver fail before then, Voyager would be rendered incommunicado, and studies of the eighth planet would be impossible even though the craft would fly past Neptune.

Voyager's propellant reserves have held out better than the craft itself. The spacecraft currently has enough hydrazine fuel to change its velocity by a total of 70 meters per second (that's 250 kilometers per hour). Although a tiny portion of that will go to keeping the antenna aimed at Earth, the bulk of it will go to changing the trajectory either to correct for navigation errors or to improve the scientific studies.

The reserves seem ample. Up to a third of the supply can be lost without affecting the plans for the Grand Tour. If more than two-thirds were lost, the flight from Uranus to Neptune would be in jeopardy. Between those levels, Voyager would have to fly a less interesting path through Neptune's system. Almost the entire supply would have to be lost for the craft not to reach Uranus.

Only a leak in the propellant system or the need to unexpectedly and repeatedly fire the thrusters could endanger the Grand Tour. While neither is likely, the navigators plan to take every chance to save even a few percent of the supply. For example, planetary encounters normally are executed so that the spacecraft reaches the point of closest approach at a specific time. Achieving that accuracy requires trajectory corrections just prior to the flyby. At Uranus and perhaps Neptune, the navigators will allow the arrival time to vary by several minutes. (That might not seem like much after eight years in flight, but it makes a great difference in knowing where to point the instruments.) The strategy will save 2.5 to 10 kilograms of propellant — but will require the mission planning office to construct a flexible schedule for aiming the cameras and spectrometers.

For the Jupiter-Saturn portion of the mission, the Voyager mission planning office looked at 10,000 different possible trajectories. By contrast, celestial mechanics offers just a handful of choices at Uranus. To continue on to Neptune, the spacecraft *must* use a gravity assist maneuver that increases its speed by almost two kilometers per second and bends its trajectory by 23° — nothing else will work. The only path that meets these requirements carries Voyager 107,080 kilometers to the right of the planet and then behind it.

Fortunately, this path provides a good flyby. The spacecraft passes close to the orbit of the innermost moon, Miranda. At the same time, the craft passes close to Uranus itself, deep inside any magnetosphere possessed by the seventh world. And, as seen from the Earth, the spacecraft will pass behind the planet and the rings, allowing the radio beam to probe the structure of both the upper atmosphere and the rings. Even if Voyager weren't continuing on to Neptune, the navigators still would stick to this same basic trajectory. Any changes would be on the order of fine tuning.

The choices left to the navigators lie primarily in the flyby's timing. Without propellant, the approach to Uranus would have been fixed by the Saturn flyby. With propellant, the navigators can use Voyager's engines to speed or slow its flight, thus creating a choice of arrival time spanning several days. This is important, as we shall see.

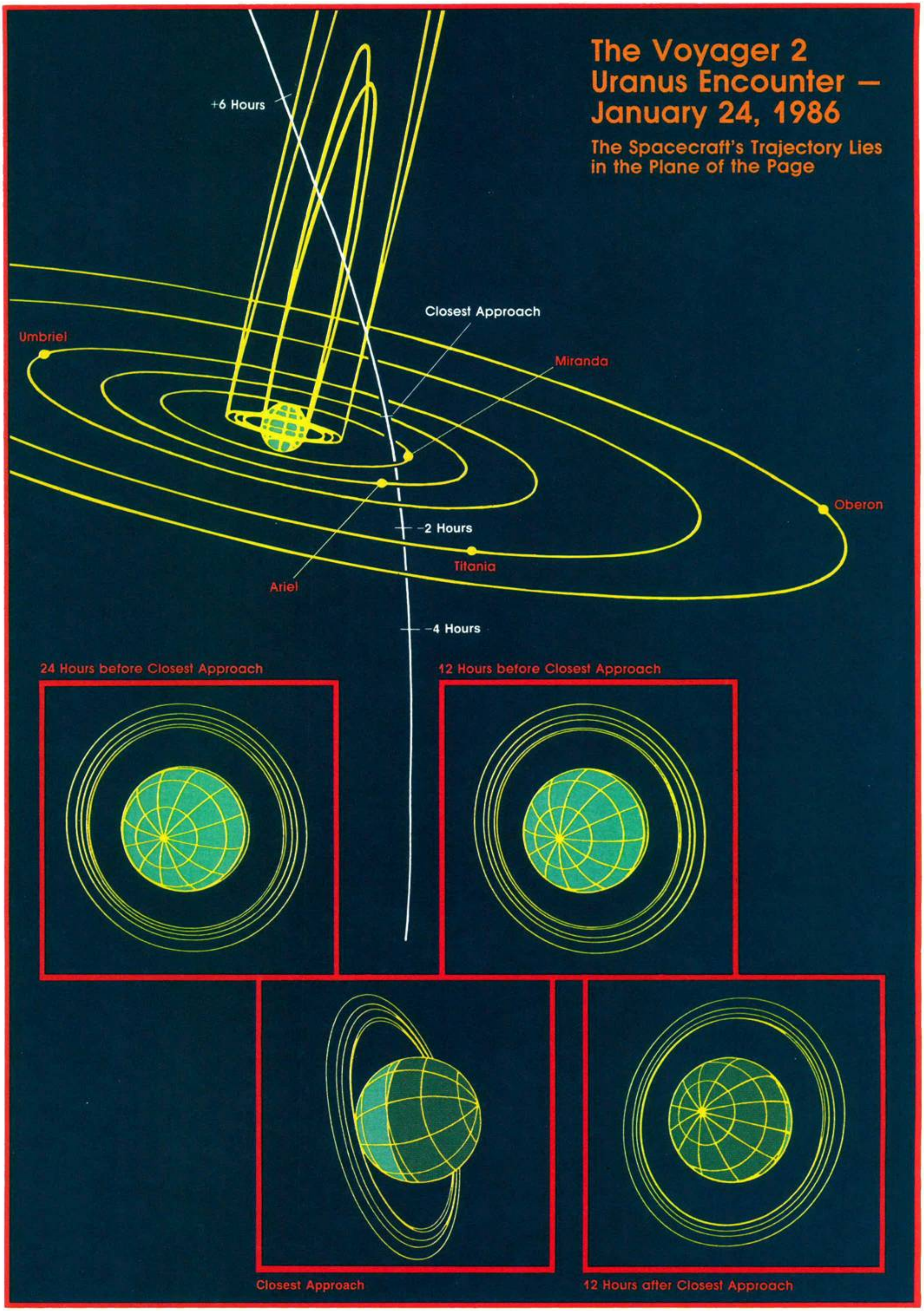
Voyager can reach the seventh planet any time between January 22 and 30 and still continue on to Neptune. For most of the experiments, one day is as good as another. The geologists, though, want to time the flyby so the craft comes as close to as many of the five known moons as possible. No date is perfect; one or more of the satellites is always near its farthest point from Voyager's trajectory.

Two attractive compromises fall on dates just outside the permissible range: January 21 and 31. The next-best option falls on January 24, the date selected for the flyby. Voyager will catch the two inner moons at close range and the three outer moons at so-so ranges. Depending on the exact timing of the flyby, the spacecraft should pass between 15,000 and 50,000 kilometers from the innermost moon, Miranda — the closest Voyager 2 has come to a world since it left Earth.

Another constraint comes from spacecraft communications. Since Uranus now lies near the southernmost point of its orbit, the southern stations in NASA's Deep Space Network are best for receiving data.

The Voyager 2 Uranus Encounter — January 24, 1986

The Spacecraft's Trajectory Lies in the Plane of the Page


+6 Hours
Closest Approach
Umbriel
Miranda
Oberon
−2 Hours
Titania
Ariel
−4 Hours

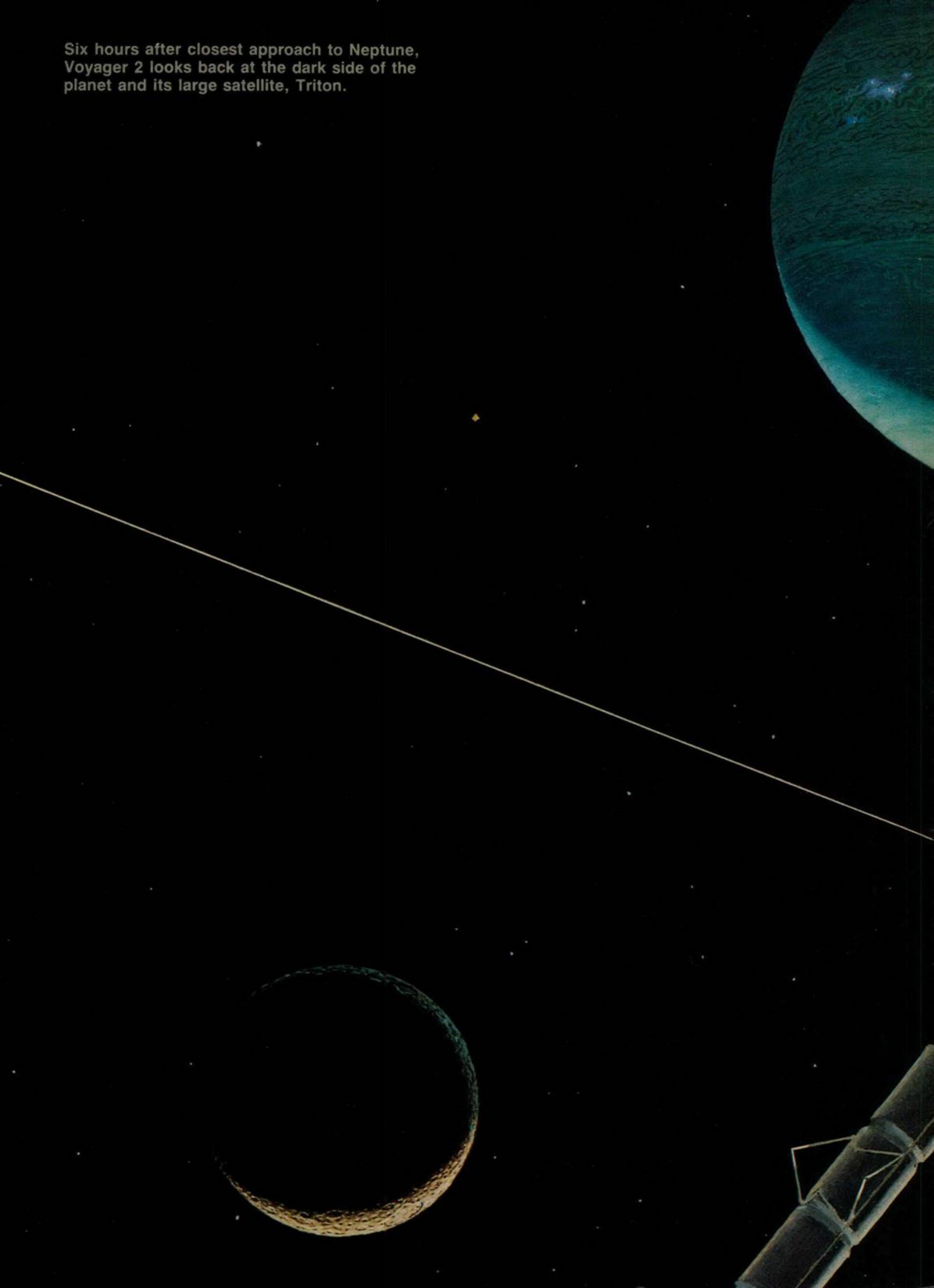
24 Hours before Closest Approach

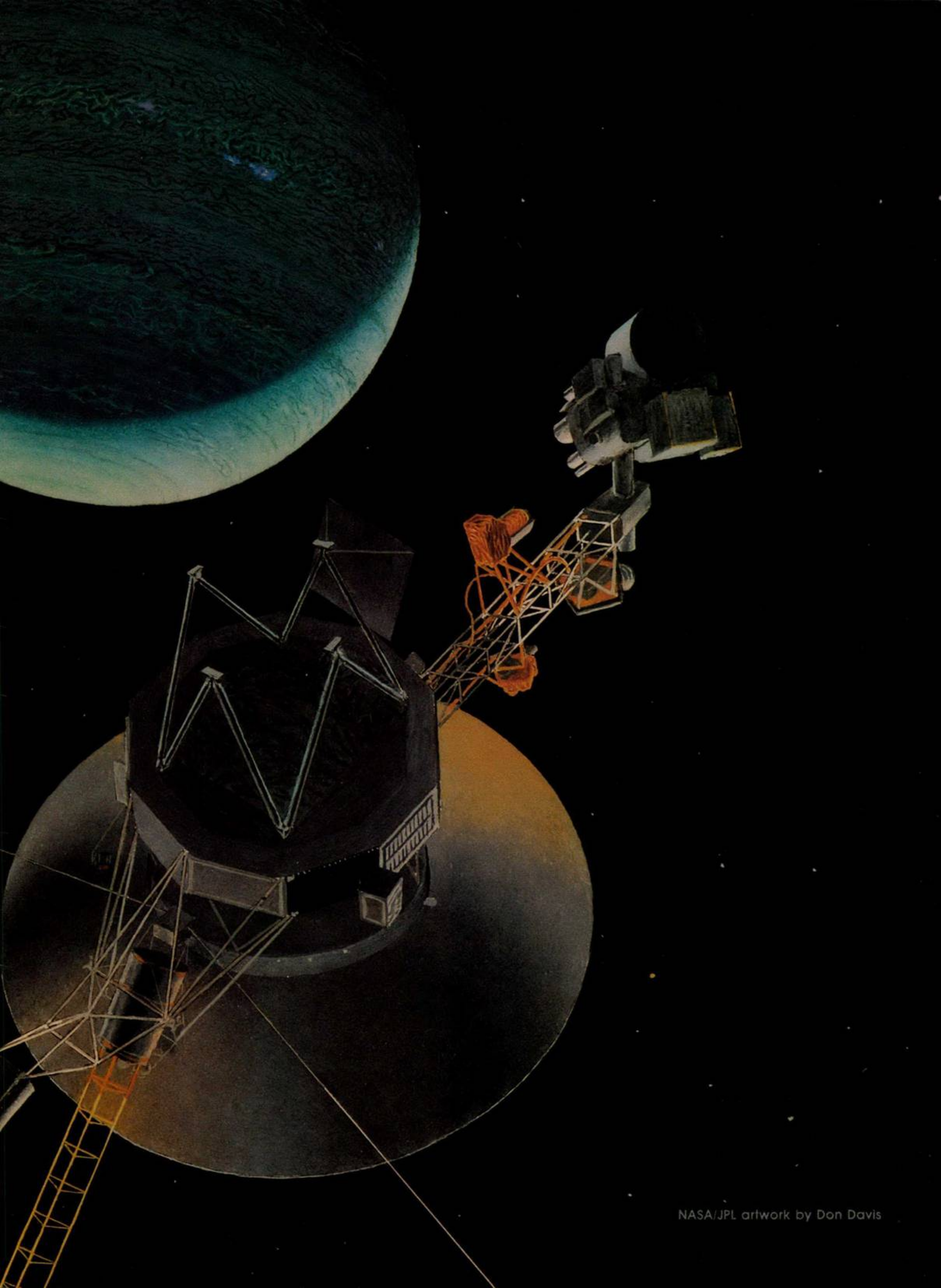
12 Hours before Closest Approach

Closest Approach

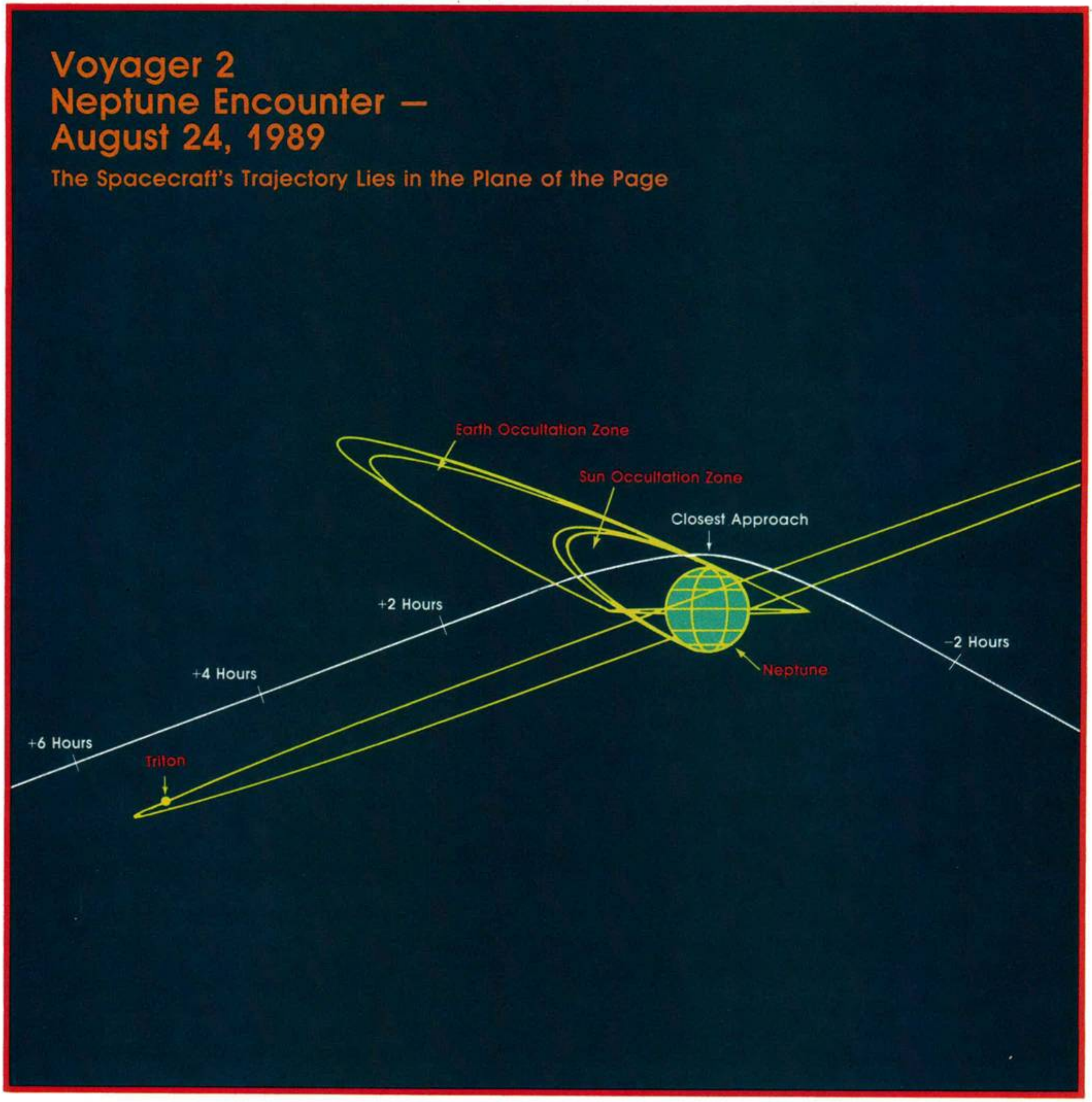
12 Hours after Closest Approach

Six hours after closest approach to Neptune, Voyager 2 looks back at the dark side of the planet and its large satellite, Triton.





NASA/JPL artwork by Don Davis



Voyager 2
Neptune Encounter —
August 24, 1989

The Spacecraft's Trajectory Lies in the Plane of the Page

The northernmost, located in Spain, must point its antennas close to the horizon to hear Voyager. As a result, this station can receive less data per second than its more southerly sister stations. Therefore, all the key events of the encounter — the flybys of the moons, the closest approach to Uranus, the flight behind the planet and rings — should ideally occur between 4 p.m. and 4 a.m. GMT, when the California and Australia stations can receive the data.

Uranus will offer the scientists almost everything Saturn did. The planet is another cloud-shrouded orb. A system of rings circles Uranus. Five moons, ranging in diameter from Miranda at 500 kilometers to Oberon at 1,630 kilometers, orbit this world. Unless this planet is very different from the other giants of the outer solar system, a magnetic field should surround it.

While the variety of subjects makes the Uranus system interesting, it will also mean frustration. This planet is twice Saturn's distance from the Earth. Voyager can return data at just one quarter the rate it did at Saturn. Fortunately, most of the craft's experiments produce fairly small amounts of data. At worst, their studies may be slightly curtailed. The cameras, though, are the data hogs. Each black-and-white photo will require some four minutes to transmit — and that's *after* Voyager's computers use special techniques to reduce the amount of data per picture. Instead of reporting the exact light intensity of every point on a photo, the craft will just report the change in intensity from point to point. If it didn't do this data compression, only a fraction of each photo could be transmitted. At best, Voyager can return between 250 and 300 pictures during the 24 hours surrounding closest approach. The flight science office figures that the minimum needed to study the system adequately would be about 330 photos: 50 of the planet, 120 of the satellites, and 160 of the rings.

Three and one-half years after leaving Uranus, on August 14, 1989, Voyager 2 will arrive at the last planet of the Grand Tour, Neptune. Because the spacecraft doesn't have to leave Neptune's system headed in any particular direction, the mission planners have a nearly free hand to design the best encounter possible. The major constraint on their work is obvious: the trajectory can't lead to a collision with the planet, its moons, or any possible rings. The choices make planning an encounter for Neptune and Triton a challenge. Each group of scientists has its own, often conflicting, priorities:

- The radio science team wants the spacecraft to pass behind Neptune and its satellite Triton so the radio beam can be used to probe their atmospheres. If any rings do exist around the planet, the radio group also wants to study their structure by flying behind them.
- The fields and particles experimenters want to penetrate Neptune's magnetosphere as deeply as possible so they can be sure to examine all of its major parts.
- The imaging group wants to fly close to Triton so the cameras can record as much geological detail as possible.

The mission planners easily discarded most of the dozens of possible trajectories because they didn't give all the scientists what they wanted. Two groups of options, though, stood out.

The first group of trajectories, nicknamed *Strawman* by trajectory designer Andrey Sergeyevsky because they originally were the leading candidates, pass Neptune on its eastern side. The Strawman missions give the best views of Triton and would allow the craft's cameras to photograph one full hemisphere. Radio scientists also would get good occultations of both the moon and planet. However, Voyager would pass too far from Neptune for good studies of the magnetic field and any rings.

The mission planners have settled on the second group of trajectories. Nicknamed *Polar Crown*, they pass over Neptune's north pole with just 7,500 kilometers between the spacecraft and the cloud tops at closest approach. Five hours and seventeen minutes later, Voyager makes its closest approach to Triton. Examined thoroughly by trajectory analyst Bob Ceserone, the Polar Crown encounters provide the best compromise between the desires of the mission's scientists. The radio science team gets its occultations of both worlds plus a possible occultation by any rings that Neptune might possess. The fields and particles researchers get the deepest penetration of any magnetic field by either Voyager.

The geologists, though, won't get the chance to photograph Triton as thoroughly as they'd like. Voyager will come at the moon from over its northern hemisphere. The cameras will photograph less than half the surface, and the terrain Voyager can photograph won't be imaged in much detail. Current plans call for the craft to pass 50,000 kilometers from Triton — close enough, in theory, for the cameras to record features smaller than a kilometer. In reality, the high flight speeds, long exposures required by the dim sunlight, and the tiny jitters of the spacecraft will smear the images. If Voyager's scan platform continues to operate properly, the craft can compensate somewhat by moving the cameras to track Triton for a wide-angle camera resolution of some 25 kilometers and a narrow-angle camera resolution of 10 kilometers. Without the compensation, the resolutions would be almost twice as bad.

Furthermore, if the situation for transmitting image data was poor at Uranus, how bad is it at Neptune? Actually, surprisingly good: NASA may manage to maintain the Uranus data rate by simultaneously listening with two tracking stations, or with the aid of other radio telescopes. Should Neptune turn out to have rings or additional satellites, the higher data rate would be a boon. If not, then scientists can give extra attention to Neptune and its moon Triton. (The other confirmed satellite, Nereid, has such an eccentric orbit that Voyager won't come close to it.)

Triton, in fact, has so intrigued researchers that the Neptune encounter is likely to be a two-world show. Measurements of its size show that Triton is larger than the planets Mercury and Pluto. Spectroscopic studies of the light reflected from Triton show it to be mostly covered by water ice with a coating of rock and soil. That much is normal.

But everything else about Triton is unusual. Some astronomers have reported that it, unlike any other moon, has continent-sized patches of methane ice. Other astronomers have reported that Triton, like Pluto, has an atmosphere of methane that's perhaps one ten-thousandth as thick as the Earth's atmosphere. (Only one other moon, Saturn's Titan, has an atmosphere. It is mostly nitrogen and nearly twice as thick as the Earth's.)

Triton's orbit also puts it into a class by itself. It follows a path that's inclined 160° to Neptune's equator, and circles Neptune in the direction opposite to that of the planet's spin. Some celestial mechanics experts believe that the moon is slowly spiraling toward its mother planet. If so, a few million years from now the tides caused by Neptune's gravity will rip the moon apart and form a ring around the planet.

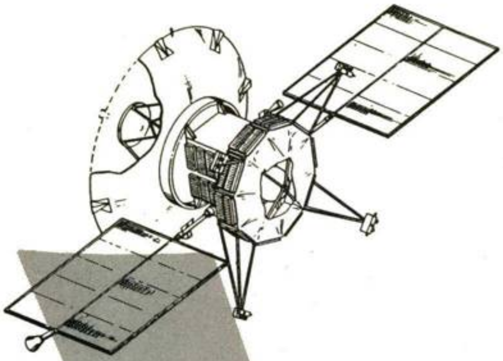
And what of Pluto? Pluto lies off to the side, impossible for Voyager 2 to reach from Neptune. After Neptune encounter, Voyager will continue on into space, continuing to record the conditions of the tenuous gas that flows outward from the Sun.

On Christmas Day, 1985, Voyager will lie 38 million kilometers away from Uranus — almost the distance between the orbits of Venus and Earth. Yet the photos will show twice the detail ever seen through a telescope on Earth. Voyager's narrow-angle camera is, in reality, a small telescope of high quality, but its optics provide no more power than the telescopes amateur astronomers use. What gives it so much power is its location — *millions, rather* than billions, of kilometers away.

On Christmas, the photos will show features 3,000 kilometers across; the next day's will show features 2,900 kilometers across; and so on until at closest approach they'll show features just 20 kilometers across. At Jupiter and Saturn, each day's new details brought new discoveries and understanding. If Voyager has done anything, it's taught us that the less we know of a world, the more it will surprise us.

And we know very little about Uranus and Neptune.

Van R. Kane, a frequent contributor to AstroNews, is a free-lance technical writer living in the San Francisco Bay area. Charles Kohlhase is manager of the Voyager mission planning office at JPL.



VEN

RADAR MAPPING MISSION

by Warren W. James

Shining in the morning or evening sky is a sharp point of light known as Venus. The ancients equated this pure white "star" with the goddess of love, but today we recognize it as another planet orbiting the Sun. But like a coy goddess hiding behind a veil, Venus remains enigmatic because thick unbroken clouds hide what lies beneath. That situation is about to change.

Radar observations, some made from the Earth and others by the Pioneer Venus Orbiter, have shown us limited, tantalizing glimpses of the hidden planetary surface (see "A World Revealed," ASTRONOMY, March 1981). But in as few as six short years, we could be looking at detailed maps of the entire planet made by a Venus orbiting spacecraft called Venus Radar Mapper.

This mission is now under study at the Jet Propulsion Laboratory. NASA's planetary science advisors have selected its scientific objectives with an eye toward maximizing our understanding of Venus. The mission has been thoroughly analyzed and its requirements are well understood. A preliminary design for the spacecraft has been completed, and a mission, using that spacecraft, has been designed. The next step for VRM is to get administrative and congressional approval for an official NASA new start in Fiscal Year 1984. If that happens, then the mission will fly essentially as it is now planned.

The VRM mission relies on a technique called synthetic aperture radar to produce images that have photographic clarity. It will reveal features as small as one kilometer through the clouds. The mission will cover over 70% of the surface of Venus, and the images will allow scientists to investigate the complex geological processes that we suspect occur there. In a sense, though, any mission to Venus is a mission to Earth. Why? The similarities and differences between Venus and Earth allow comparisons which can serve as sensitive tests for our models of planetary phenomena. In a very real way, understanding of Venus means gaining an understanding of the Earth, too.

What exactly will the spacecraft do? First, it will make radar maps to identify the different geological areas on Venus. Other instruments will study the topography of the venusian surface and the variations in its gravitational field, allowing us to probe the planet's interior. The data from this mission are crucial for our studies of geology, planetary physics, and comparative planetology because of the unique characteristics of Venus.

Despite the scientific importance of geologically mapping Venus, NASA has had great difficulty in obtaining the money to do so. An earlier proposal for a mission to map Venus, called Venus Orbiting Imaging Radar, was studied extensively during the 1970s (see "Alien Eyes," ASTRONOMY, January 1980). The VOIR mission featured a custom-designed spacecraft and carried experiments to study the atmosphere of Venus. Mission planners decided to operate this spacecraft from a circular orbit around Venus but found that getting the spacecraft into that orbit was a challenging technical problem. They studied a variety of systems for getting VOIR into that circular orbit and concluded that a system called aerobraking would be the most cost-effective.

VOIR was proposed as a new project several times, but was rejected each time because of its $700 million cost. Finally in January 1982, VOIR was postponed indefinitely.

Rather than accept an end to America's role in the study of Venus, the scientists, engineers, and administrators at NASA and JPL went to work to see if there was any way to get the most important data VOIR would have provided at a lower cost. Fortunately, it was possible: the VRM mission. VRM does double duty, too, for it serves as a prototype for future "budget" missions to the planets.

The first task was to tightly focus the scientific objectives. Instead of trying to do studies of the solid body of the planet as well as its atmosphere, as VOIR had, the VRM mission will study only the surface of the planet. Mission scientists next decided what observations were necessary to satisfy the scientific objectives of the mission. VRM had to meet the needs of the geologists, but the observations could not exceed those absolutely necessary. VOIR, for example, had a radar system that would have mapped Venus at 1000 meters resolution and also at 150 meters resolution. The 150-meter observations were desirable, but they increased the cost of the radar system. Scientific study showed that the data would be helpful but not crucial, so the scientists decided they could do without it.

Other areas of the VOIR mission were studied to see why they cost so much. Putting the spacecraft into a circular orbit created a number of expensive requirements. Spacecraft that orbit other planets are generally put into elliptical orbits because they require a smaller velocity change when the craft arrives at the planet. The larger the velocity change, the more massive the spacecraft propulsion system must be, and the larger that system, the more complex it will be; thus its cost will rise. The mission designers went to work to design a mission that could be done from an elliptical orbit. The radar system designers redesigned the radar system so it was able to operate from an elliptical orbit. The mission designers could then put together a mission that did not require a circular orbit but would still return the data that the scientists needed.

Finally, the spacecraft engineers looked at cheaper ways to design and build the spacecraft. VOIR was a custom-designed spacecraft; it was optimum for the mission, but also quite expensive. For VRM, the spacecraft engineers looked around to see if it would be possible to build a Venus-orbiting spacecraft from parts that had been designed or built for other missions. It turned out that they could assemble a suitable spacecraft from leftover parts from Voyager and Galileo. The resulting design needs only about 30% custom-designed hardware, dramatically lowering the cost of the spacecraft.

When all is said and done, VRM is a mission designed to cost less than $300 million, yet able to meet the most important scientific objectives of the $700 million VOIR mission. VRM sets the tone for future planetary missions — missions with focused scientific objectives selected to increase our understanding of the planet as much as possible. The new missions will be designed with a sensitivity to cost so that no single feature drives up the total price. And they will use existing hardware or hardware designs whenever possible.

Why Is Venus an Interesting Planet?

Why does a mission to Venus deserve so much effort? The past several decades of Earth-based and spacecraft observations have shown us that Venus is similar to Earth in many of its basic characteristics: size, mass, mean density, and distance from the Sun. This might imply that Venus also mimics Earth in many of its detailed characteristics.

But nothing could be farther from the truth. Venus is hellishly different from Earth in almost all of its detailed characteristics. Its atmosphere is 90 times more massive than Earth's. Temperatures on the surface of Venus are around 900° F. The atmosphere is predominantly carbon dioxide with small amounts of nitrogen, argon and various other gases. Its clouds are composed of a concentrated sulfuric acid solution. Venus rotates in a retrograde direction once every 243 days. It lacks a large magnetic field. The distribution of basic crustal materials on Venus is apparently different from that on Earth. On Earth there are two main values for surface elevation — the elevation of the ocean basins and that of the continents. This bimodal distribution of elevations is thought to be related to fundamental differences in the composition of the two different crust types. On Venus, the elevations seem to be randomly distributed around the mean planetary radius.

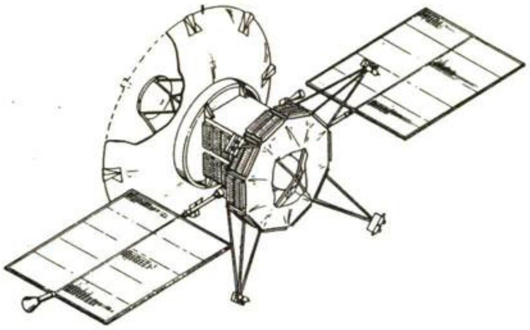
On Earth there is no correlation between the large-scale structure of its gravitational field and its large-scale topography. Since gravity is caused by the presence of matter, you might expect that the measured gravity would increase over mountains and continents and drop over lowlands and ocean basins. But this is not the case on Earth; the interior rocks cannot support the weight of large, high-density structures, so they sink into the Earth. Large, low-density structures tend to float. Earth's topographic features tend to cancel out the expected variations in gravity.

On Venus, however, Pioneer Venus observed that the gravitational field is tied quite closely with the local topography. Why is Venus different from Earth? What does this difference imply about the interior of Venus?

The most fundamental geological property of the Earth is that it is divided into a rigid lithosphere and a deformable inner region called the mantle. Heat transfer within the mantle is by convection. This is a movement of the material within the Earth caused by buoyancy forces, which are caused by temperature differences within the planet. The movement of this material transfers the heat from within the Earth to its surface, where it is radiated away into space. Stress caused by these motions within the Earth causes the lithosphere to break into plates, which are then rafted about by these subsurface motions. The motion of the plates is responsible for the broad-scale structure of the Earth. In some places, the *upwelling of* material from within the Earth creates new crustal material, which is then transported away from its place of birth, forming ocean basins. In other places, plates collide. Depending on their relative densities, they may buckle upward, forming mountain ranges, or be forced down into the mantle and recycled.

Data from the Pioneer Venus orbiter have shown the topographic profile of Venus, but cannot definitively answer the question, "Does Venus have plate tectonics?" The only thing we can say about Venus is that its style of global tectonics is certainly different from that of the Earth. The question that remains is "Why?"

With two decades of spacecraft exploration of Venus behind us, we might expect to have enough information to really understand Venus. Unfortunately, this is not the



case. Most missions to Venus have been designed for studies of its perplexing atmosphere, not for geology and geophysics.

When previous missions studied the geology of Venus, they either obtained a lot of low-resolution data or a little high-resolution data. Both kinds of data are important, but neither alone can answer our questions about the global geology of Venus. The Pioneer Venus orbiter radar altimeter experiment mapped the topography of the entire planet, but it did this at resolutions of around 100 kilometers. This is fine for looking at the broad characteristics of the planet, but is not adequate for exploring the geology of Venus.

The Soviet Venera lander surface photography showed much small-scale detail, but we have no way to accurately understand those highly localized observations in any kind of global context. Just for comparison, imagine the difficulty a venusian scientist would have if you went behind your house, took a photograph of the ground near your feet, and then asked him to interpret the geological characteristics of the entire United States from it!

So, how will VRM actually obtain data about the surface of Venus? The data will come from three experiments. The first is the synthetic aperture radar (SAR), which will use radar to make photographic quality images of the surface of the planet. The second experiment will use a part of the radar electronics to operate an altimeter, accurately measuring the topography of the planet. The last experiment will measure the gravitational field of the planet by accurately tracking the spacecraft's orbit.

The most important experiment is the SAR. It will give us the capability to make photographic quality images of the surface of Venus. Radar works by transmitting a beam of microwaves toward the surface of the planet. When they are reflected off the surface, we have the opportunity to measure three properties. The first is the time required for the signals to return to the spacecraft, a measure of how far they have traveled. Second, because these signals are transmitted perpendicular to the direction of the motion of the spacecraft, they will be doppler-shifted by the relative motion of the spacecraft and the planet. Finally, the strength of the returned signals depends in a complex way on the nature of the surface. By analyzing the signals in a computer, it is possible to determine where each bit of the signal came from and how it was reflected; these points can then be mapped to standard coordinates on the surface of the planet.

The maps, needless to say, are not photographs taken in visible light, but radar images. The appearance of the image is dictated by the characteristics of the radar system

Building Planets: a lesson in comparative planetology

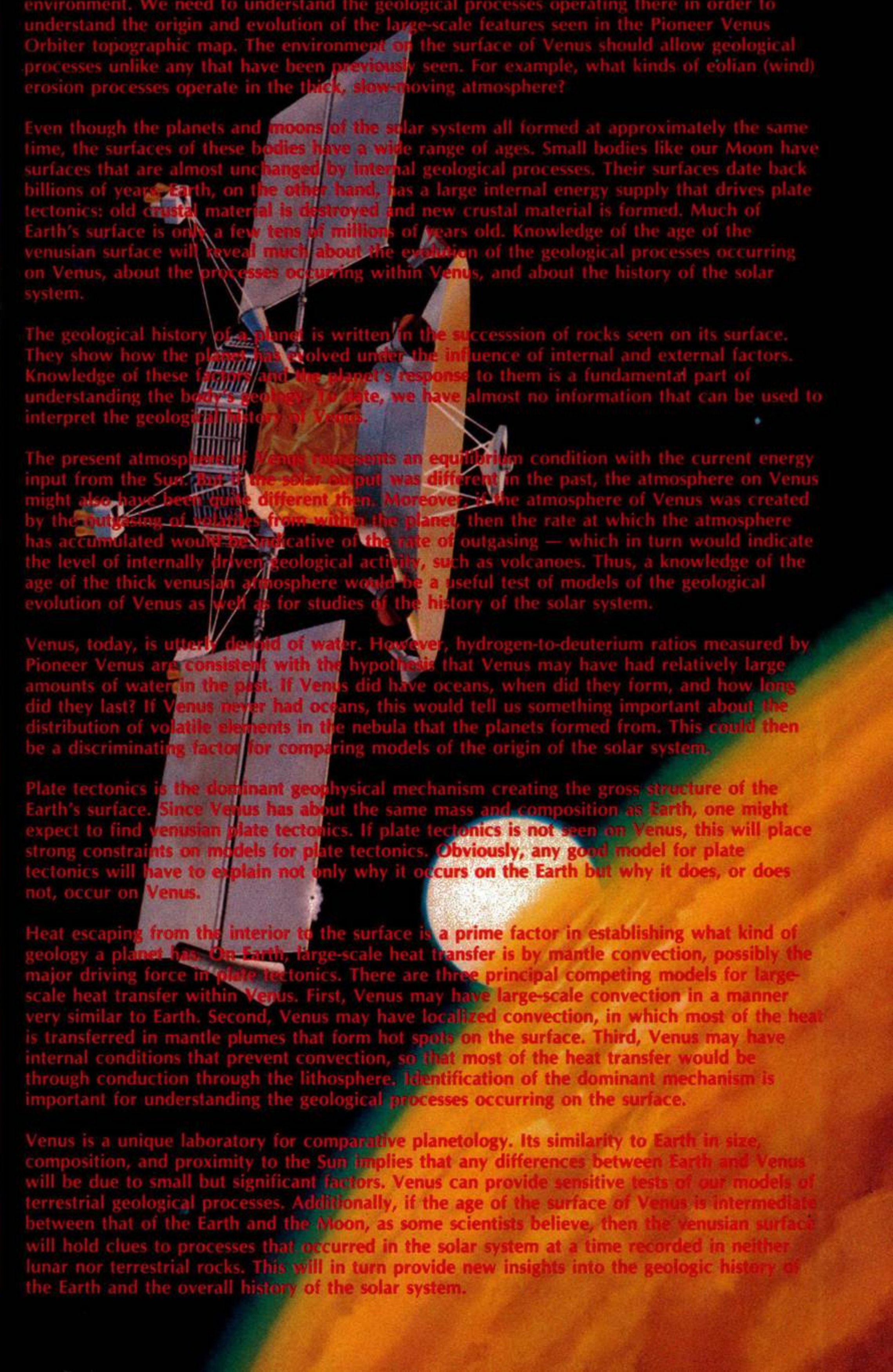
The laws of physics do not change from one planet to the next, so it seems reasonable to expect that if you have two planets composed of similar amounts of similar materials, then their geology, geophysics, and meteorology will be similar. Yet Venus is completely unlike Earth. This must mean that certain subtle factors in a planet's makeup can have major effects on its evolution.

Imagine that we have a black box (i.e., a scientific model) that describes everything that we understand about planetary physics. If we give that box a sufficiently detailed input (i.e., the planet's size, mass, composition, initial thermal state, and relevant external factors), then this black box should be able to predict the most important characteristics of that planet today. Since the laws of physics apply on all planets, that black box should allow us to describe any planet. Now, presume that we have tested that black box, and it works well for one planet. If we used that black box to study another planet, and the predictions it made also matched the observations, then we would have some confidence that our model is in good working order.

However, suppose it made incorrect predictions. We would then have to worry about its accuracy. Additionally, if small changes in the input parameters produced only small changes in its output, then our model would not have to be very sensitive to work acceptably well. But if small changes in the input conditions caused large changes in the output parameters, then the model would have to be quite sensitive to work well.

This is one reason why Venus is important. Its similarity to Earth in bulk properties combined with dissimilarity in detailed characteristics may provide us with sensitive tests for many of our models for planetary phenomena.

Important Questions About Venus



NASA/JPL artwork by Ken Hodges

What processes operate to form and modify the surface of Venus?

Venus is a world similar in size to Earth, but with a dramatically different surface environment. We need to understand the geological processes operating there in order to understand the origin and evolution of the large-scale features seen in the Pioneer Venus Orbiter topographic map. The environment on the surface of Venus should allow geological processes unlike any that have been previously seen. For example, what kinds of eolian (wind) erosion processes operate in the thick, slow-moving atmosphere?

What is the age of the surface of Venus?

Even though the planets and moons of the solar system all formed at approximately the same time, the surfaces of these bodies have a wide range of ages. Small bodies like our Moon have surfaces that are almost unchanged by internal geological processes. Their surfaces date back billions of years. Earth, on the other hand, has a large internal energy supply that drives plate tectonics: old crustal material is destroyed and new crustal material is formed. Much of Earth's surface is only a few tens of millions of years old. Knowledge of the age of the venusian surface will reveal much about the evolution of the geological processes occurring on Venus, about the processes occurring within Venus, and about the history of the solar system.

What is the geological history of Venus?

The geological history of a planet is written in the successsion of rocks seen on its surface. They show how the planet has evolved under the influence of internal and external factors. Knowledge of these factors and the planet's response to them is a fundamental part of understanding the body's geology. To date, we have almost no information that can be used to interpret the geological history of Venus.

How old is the present atmosphere?

The present atmosphere of Venus represents an equilibrium condition with the current energy input from the Sun. But if the solar output was different in the past, the atmosphere on Venus might also have been quite different then. Moreover, if the atmosphere of Venus was created by the outgasing of volatiles from within the planet, then the rate at which the atmosphere has accumulated would be indicative of the rate of outgasing — which in turn would indicate the level of internally driven geological activity, such as volcanoes. Thus, a knowledge of the age of the thick venusian atmosphere would be a useful test of models of the geological evolution of Venus as well as for studies of the history of the solar system.

Did Venus ever have water and oceans?

Venus, today, is utterly devoid of water. However, hydrogen-to-deuterium ratios measured by Pioneer Venus are consistent with the hypothesis that Venus may have had relatively large amounts of water in the past. If Venus did have oceans, when did they form, and how long did they last? If Venus never had oceans, this would tell us something important about the distribution of volatile elements in the nebula that the planets formed from. This could then be a discriminating factor for comparing models of the origin of the solar system.

Does Venus have plate tectonics?

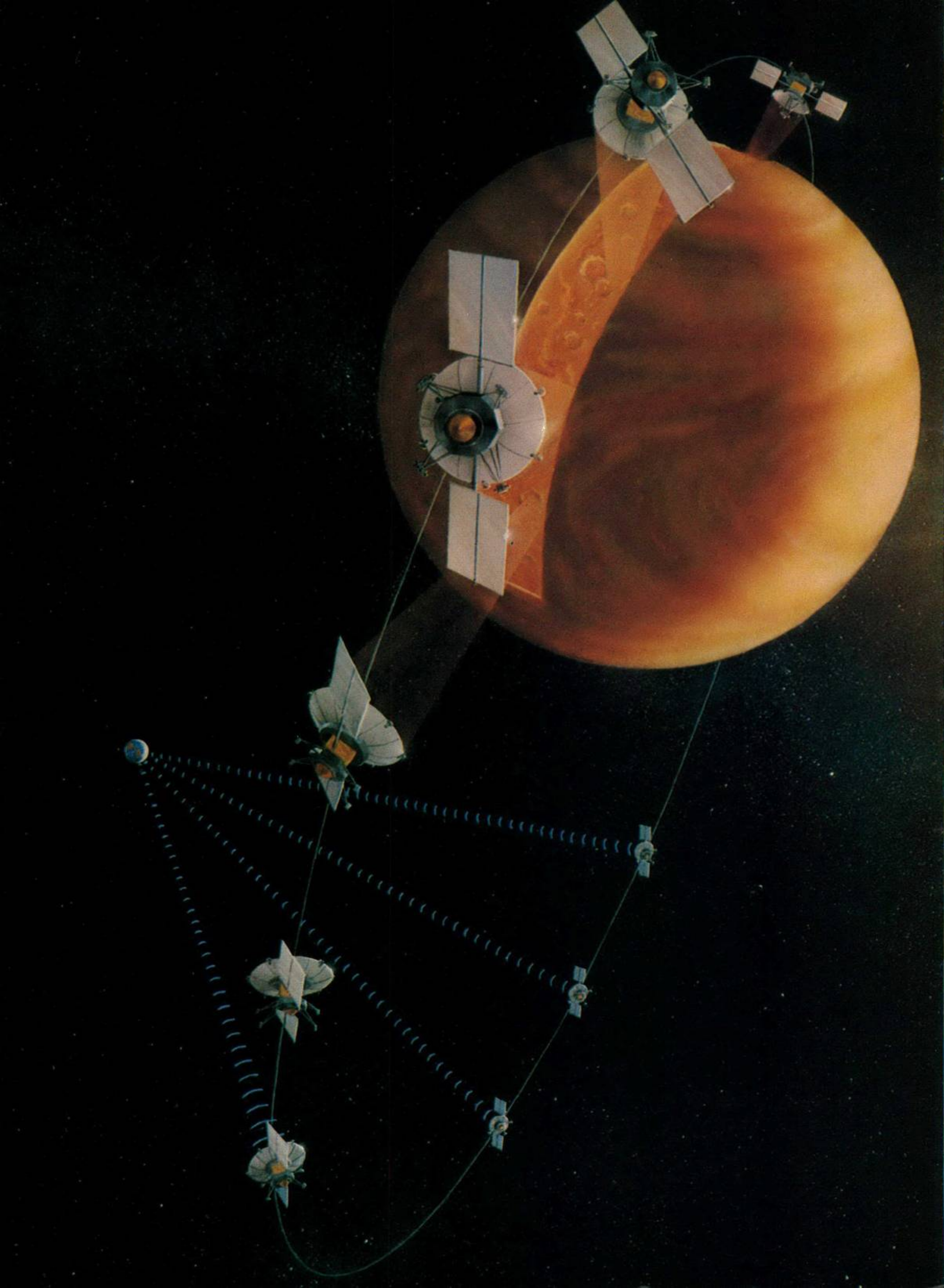
Plate tectonics is the dominant geophysical mechanism creating the gross structure of the Earth's surface. Since Venus has about the same mass and composition as Earth, one might expect to find venusian plate tectonics. If plate tectonics is not seen on Venus, this will place strong constraints on models for plate tectonics. Obviously, any good model for plate tectonics will have to explain not only why it occurs on the Earth but why it does, or does not, occur on Venus.

How does heat escape from the interior of Venus?

Heat escaping from the interior to the surface is a prime factor in establishing what kind of geology a planet has. On Earth, large-scale heat transfer is by mantle convection, possibly the major driving force in plate tectonics. There are three principal competing models for large-scale heat transfer within Venus. First, Venus may have large-scale convection in a manner very similar to Earth. Second, Venus may have localized convection, in which most of the heat is transferred in mantle plumes that form hot spots on the surface. Third, Venus may have internal conditions that prevent convection, so that most of the heat transfer would be through conduction through the lithosphere. Identification of the dominant mechanism is important for understanding the geological processes occurring on the surface.

What can Venus tell us about Earth's history?

Venus is a unique laboratory for comparative planetology. Its similarity to Earth in size, composition, and proximity to the Sun implies that any differences between Earth and Venus will be due to small but significant factors. Venus can provide sensitive tests of our models of terrestrial geological processes. Additionally, if the age of the surface of Venus is intermediate between that of the Earth and the Moon, as some scientists believe, then the venusian surface will hold clues to processes that occurred in the solar system at a time recorded in neither lunar nor terrestrial rocks. This will in turn provide new insights into the geologic history of the Earth and the overall history of the solar system.



NASA/JPL artwork by Alan Gutierrez

and by the distance from the planet. There are, for example, radar shadows in areas where the local topography blocks the microwaves — something of a problem. On the other hand, since the spacecraft provides the "illumination," there is no need to make maps only of the daytime side of the planet. Radar uses wavelengths that are longer than those used for optical imaging systems — so the radar reflection will be sensitive to different physical characteristics. In an optical photograph, the reflectivity of a picture point is primarily a function of the chemical composition of the surface. In radar pictures, the reflectivity depends mainly on the roughness of the surface. However, the most important thing to remember about radar pictures is that they look like the normal pictures used in photogeology, and can be used in pretty much the same way.

VRM: Building a Cheaper Spacecraft

VRM had to be a low-cost mission, and the spacecraft had to be a marvel of low-cost spacecraft engineering. The greatest marvel is that even before the mission has been approved, much of the VRM spacecraft has already been built or designed. How? The bulk of the VRM spacecraft will come from Voyager prototype units that were built for Voyager preflight testing. These units are now sitting in storage, unused.

Voyager hardware to be used includes the spacecraft bus, the 3.7-meter antenna, which will be used for the SAR and the telecommunications system, propulsion-system components, thermal control louvers, and radio-system components. Additional hardware is available from the Galileo mission flight spares stockpile — including the command and data system, the tape recorder, the attitude control processor, the power subsystem, and propulsion components. Still more hardware comes from other projects and from standard NASA designs. Only about 30% of the VRM spacecraft will have to be designed specifically for this mission: chiefly the SAR electronics, the solar panels, and some miscellaneous structures and components.

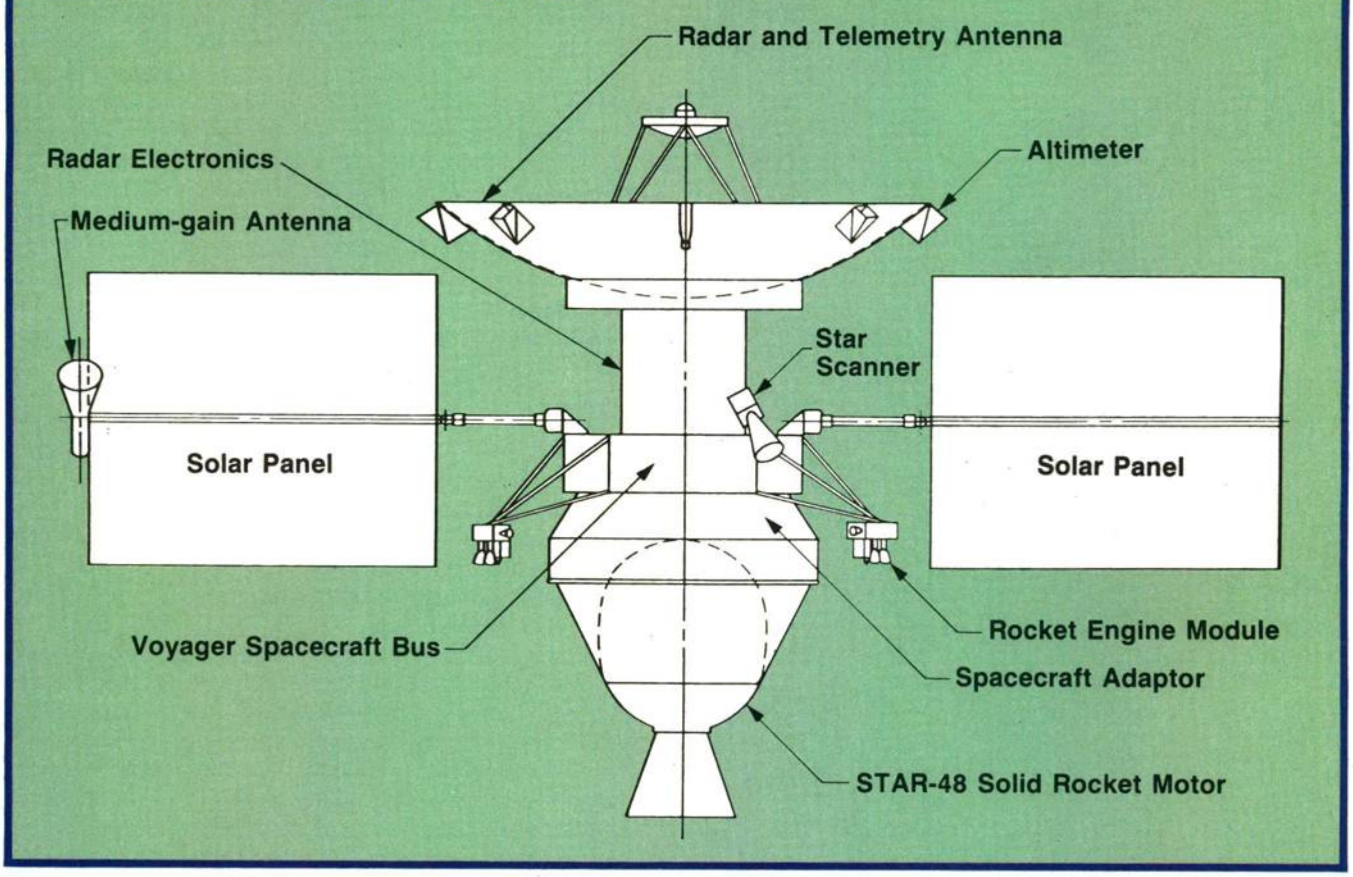
The bus will contain the command and data system, the attitude control propellant, tape recorder and other electronic components. The orbit insertion motor is a STAR-48 solid rocket motor, which will be jettisoned after the spacecraft goes into orbit around Venus. Attitude control and orbit trims will be performed using sets of liquid-propellant rocket motors located in four modules mounted on outriggers for maximum efficiency. Electrical power will be supplied by large solar panels that can rotate about a single axis to track the sun. The SAR electronics will be mounted between the bus and the antenna.

The VRM, attached to a Centaur upper stage, will be carried into a low Earth orbit by a Space Shuttle in late March or early April 1988. After reaching orbit, astronauts will check it out and deploy it from the Shuttle Orbiter. At the proper moment, the rocket motor of the Centaur will ignite and VRM will start off on an interplanetary trajectory carrying it halfway around the Sun before reaching Venus in July 1988.

When the spacecraft arrives at Venus, the STAR-48 solid rocket motor will slow it down, dropping it into an elliptical orbit passing over the planet's poles. After a ten-day checkout period to verify that all spacecraft systems are operating properly, the mapping of Venus will begin.

VRM will map Venus from an elliptical orbit having a period of 3.7 hours and minimum and maximum altitudes of 250 and 10,300 kilometers, respectively. This

The VRM Spacecraft



tradeoff introduces several complexities into the operation of the radar system. Because of the large variations in the distance to the surface caused by altitude changes in the elliptical orbit, the SAR look angle must be changed during a mapping pass in order to catch radar reflections from the planet. The VRM radar system will be able to operate between altitudes of 250 and 1900 kilometers, with look angles ranging between 51° for the lowest altitudes and 24° for the highest. Although data can be taken from higher altitudes, they won't be as good.

On each orbit, the VRM spacecraft will map a long, narrow strip of Venus. The strips will ultimately be assembled into a mosaic of the entire planet. For now, though, let's follow the spacecraft and see how it maps the planet. Imagine that we pick up the spacecraft as it approaches the lowest point of its orbit, or periapsis; it is nearly time to start the radar mapping.

The spacecraft slowly turns so that its large antenna points away from the Earth and swings into position aimed down at Venus, off to the side of the spacecraft ground track. Everything is ready. The SAR system powers up and starts to operate. As its altitude drops below 1900 kilometers, good data start to come in and are stored on the tape recorder for later transmission to Earth.

As the spacecraft continues its descent, the velocity increases with each moment. The SAR compensates, changing the look angle constantly. This is the time when the data are best. Periapsis comes quickly, and then the spacecraft starts its long climb toward the high point in its orbit. As it rises higher and higher, the SAR look angle must change again in order to preserve the quality of the imaging. As the spacecraft passes 1900 kilometers altitude, the tape recorder is full of images of Venus, and the SAR system is powered down.

The spacecraft now rotates so that its large parabolic antenna points toward Earth instead of Venus, and the tape recorder is rewound to prepare it for transmission to Earth. The high-rate telemetry signal switches on, and the tape recorder starts its replay. The observations are transmitted to Earth at 240,200 bits per second for one hour and 52 minutes. Finally, the tape recorder is emptied, and the spacecraft starts back on its way down to the planet, where the whole process will be repeated.

Each mapping pass images a swath of the planet that varies in width from 17 to 28 kilometers — each swath narrower than the Pioneer Venus altimeter could show. Since the orbital plane of the spacecraft will remain nearly fixed in space, the slow rotation of Venus will bring new areas into the view of the spacecraft with each pass.

VRM's nominal mission will last 243 days. It will observe 360° of Venus in longitude, and map 92% of the surface of Venus at 1000 meters resolution or better. The missing 8% will be near one of the poles of Venus; the best images will lie near the equator, under the low point of the VRM spacecraft's orbit.

VRM is a perfect mission for the present. The science is absolutely essential to our understanding of the solar system. The cost is low. And Venus remains the only terrestrial planet that has not been given even an exploratory geological mapping. VRM will change that.

Warren James works at JPL as a science co-ordinator for the imaging experiment on Galileo and is involved in mission engineering for the VRM mission.

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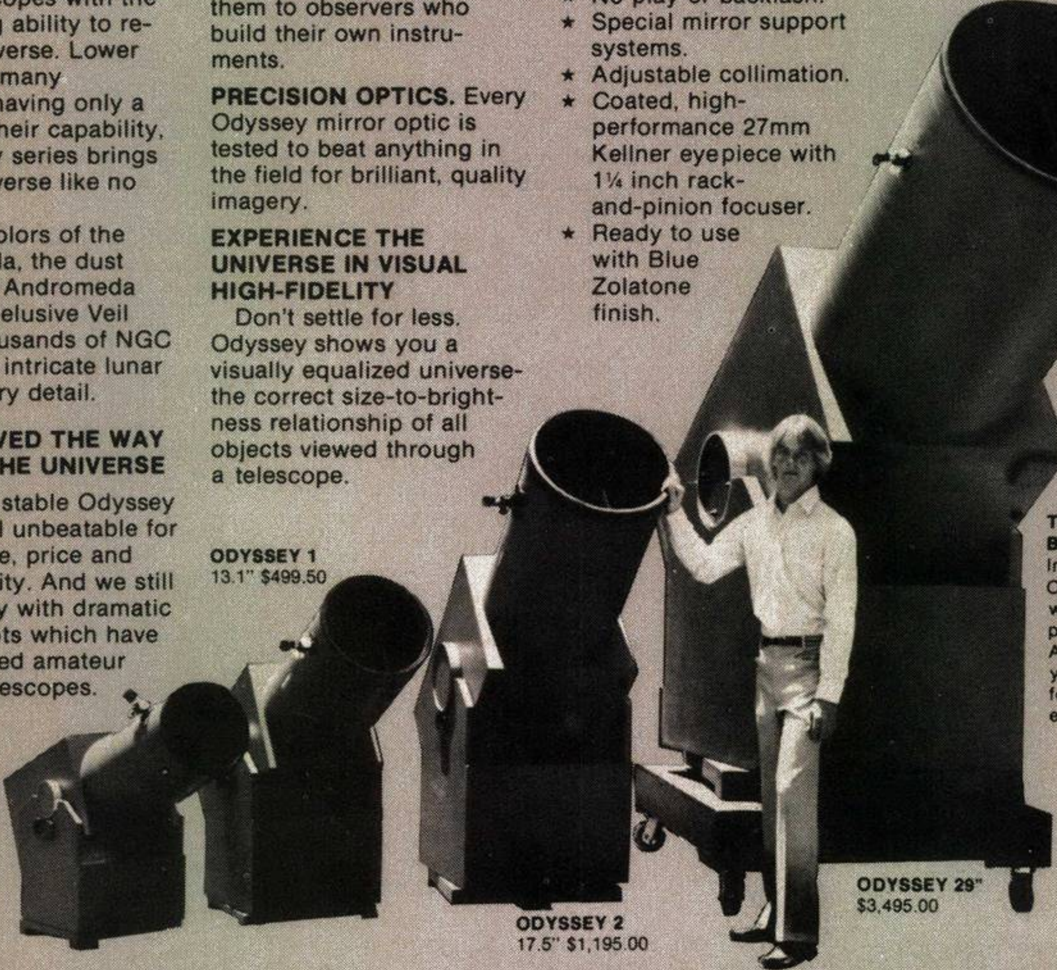

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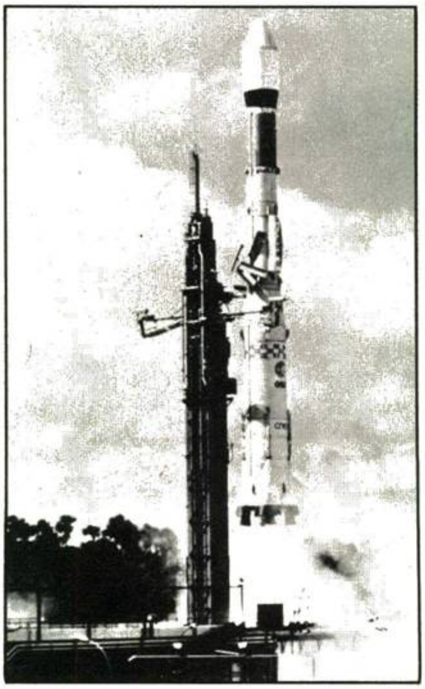
The Little Rocket that Could

With the successful launch on December 19, 1981 of the fourth and final test flight of Europe's Ariane-1, a new Atlas-Centaur class launch vehicle, the European Space Agency laid the foundation for an active future in space. Further, it brought the development of the first truly multinational large-scale space program to a successful conclusion. It would be difficult to overemphasize the potential importance of both achievements. Yet the realization of that potential largely depends upon the ultimate utilization of this new rocket — upon decisions to be made in the next year or two.

These developments will also have a considerable impact upon the United States and the Soviet Union. What is Europe's future in space, and how closely will it parallel American and Soviet experience? For the first time, the two superpowers do not have exclusive access to space. A third spacefaring power can now launch the commercial satellites, including "spy" satellites, for unaligned nations — and shows every indication of doing just that. No one can predict where all this will lead, but it will certainly mean a powerful change in the way we exploit the resources of space.

In the early 1970s, Europe realized that there would be a commercial future for space transportation in the 1980s. At that time it was by no means certain that the Space Shuttle, the only major launch vehicle under development in the United States, would ever get off the ground. More important, most U.S. expendable rockets were derived from aged military vehicles that had not been originally designed to reach geosynchronous Earth orbit — where most commercial customers would want to go. The rockets then available were most efficient at delivering heavy payloads to low orbits. So the road to successful competition was clear: build a highly specialized expendable rocket optimized for geosynchronous orbit, using the most modern technology to achieve the lowest possible recurring costs. The result was Ariane-1.

As it turned out, the Space Shuttle was fully developed and now shows every sign of achieving operational status — a seemingly fatal blow to Ariane's commercial future. But things are not that simple. First of all, the launch costs for the Space Shuttle appear to be several times those anticipated, and development costs were more than twice original expectations. These increased costs mean higher bills for commercial customers. Ariane was developed well within the upper limit of its estimated costs, even when the costs of redevelopment after the failed second test launch are included. Launch costs are expected to be only marginally more than anticipated. One can argue, of course, that the Space Shuttle breaks new technological ground, while Ariane does not. But the commercial world cares little about such matters.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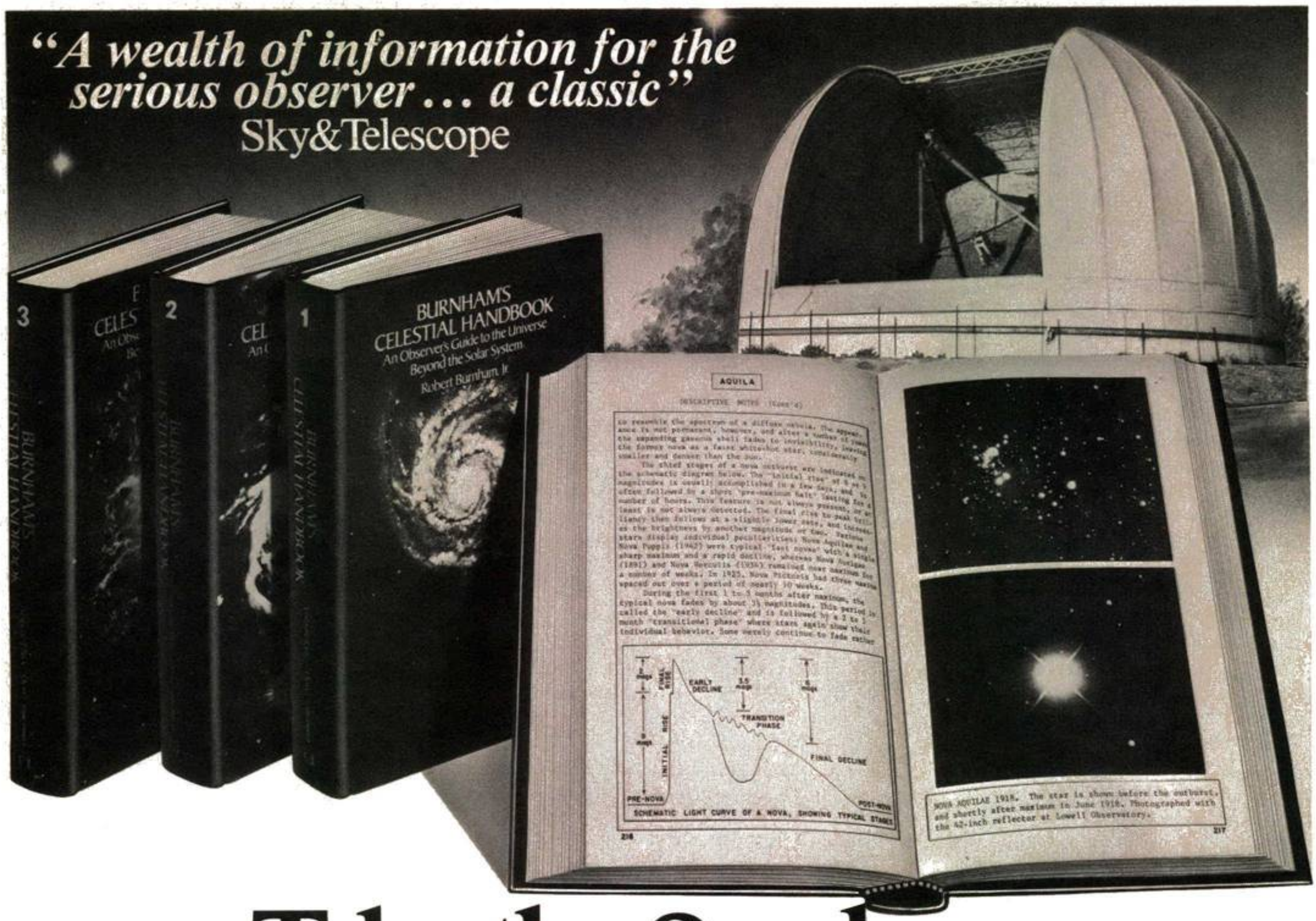
First launch of Ariane on December 24, 1979 from the Konrou space center.

What planners had claimed as the Shuttle's greatest strength may be a devastating blow to its commercial use: it is a general, all-purpose "space truck" designed to carry anything and everything into low Earth orbit. Commercial payloads destined for the 35,870-km high geosynchronous orbit must have a separate additional rocket to boost them higher than the Space Shuttle's 960-km ceiling. Worse yet, these payloads must move to a different orbital plane — one of the most fuel-expensive maneuvers possible in Earth orbit. The orbit most easily reached from Kennedy Space Center has an inclination of 28°, but communications satellites must attain equatorial (0° inclination) orbits. The actual situation is still worse than this since rockets must be launched into a less-than-perfect orbit in order to avoid the population centers around the Space Center.

Ariane, however, is launched from a site very close to the equator (Kourou, French Guiana), thereby avoiding expensive changes of orbital plane, as well as taking full advantage of the free boost provided by the Earth's equatorial rotation of 500 meters per second. This is nearly six percent of orbital velocity — well worth considering in any commercial vehicle.

Why isn't the Space Shuttle launched from the equator? Political and military requirements for locating the national space port within national boundaries took precedence over economies of operation — a good example of the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kind of thinking that is ruining the Space Shuttle's chances for commercial success.

All this means that Ariane is little more expensive than the Space Shuttle for most commercial payloads — and France has indicated a willingness to subsidize even this difference. Furthermore, Ariane offers the advantages of the tried and true over the experimental — a point repeatedly stressed in Arianespace advertising brochures.

Incidentally, Arianespace is a French company with holdings throughout Europe, and will take over "the responsibility for the production, marketing, and launching of operational Ariane vehicles and their uprated versions" starting with the seventh operational launch. Arianespace will thus become the world's first commercial space carrier, and Ariane the first commercial space transport. Plans are just beginning for the transfer of the Space Shuttle to a commercial operator.

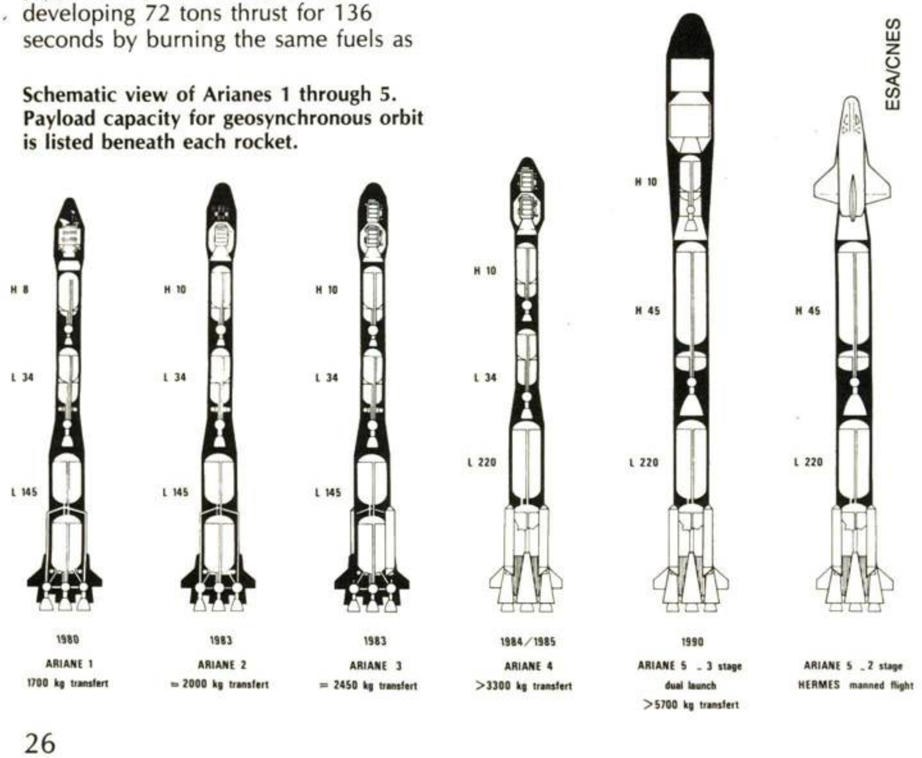
Let's look a bit more closely at this little rocket that may cast a shadow on the glories of the Space Shuttle. Ariane-1 is a conventional three-stage expendable launch vehicle weighing 210 tons at liftoff. The payload contributes only one percent of the total mass, the vehicle contributes nine percent and the remaining 90 percent is fuel — clearly demonstrating why space travel with chemical rockets is so expensive. The first stage is propelled by four Viking-5 engines developing 245 tons of thrust for 146 seconds. Propellants are unsymmetrical dimethylhydrazine (UDMH) and nitrogen tetroxide (N_2O_4). Stage two is propelled by one Viking-4 engine developing 72 tons thrust for 136 seconds by burning the same fuels as stage one. Stage three is the first cryogenic stage ever developed in Europe, and the first successful one developed outside of the United States. It is propelled by one HM-7 engine developing a thrust of six tons for 545 seconds. All together, Ariane-1 can lift 1,700 kg into geosynchronous transfer orbit, a parking orbit traditionally used to measure a launch vehicle's performance: the highest point in the orbit is at geosynchronous altitude while the low point is at about 200 km. After orbit "circularization," the final payload comes to about 1,025 kg in geosynchronous orbit.

The European Space Agency has already begun a progressive development program intended to increase Ariane's performance and ability to compete commercially. Work on Ariane-2 and 3 is already under way, and the Agency will almost certainly begin development of Ariane-4 within a few months. Ariane-5 is now under study and has a good chance of being accepted for development by 1985.

Ariane-2 will be capable of lifting 2000 kg into transfer orbit. It will increase the efficiencies of the engines on all three stages, increase the third-stage fuel load by 25 percent, and recover the first stage for partial reuse — a first for an expendable launch vehicle. Ariane-3 will deliver 2,400 kg into transfer orbit and is identical to Ariane-2, except for the addition of two to four solid rocket boosters, each containing seven tons of propellant and developing 70 tons of thrust.

In its most recent incarnation, Ariane-4 is designed to lift up to 4,300 kg into transfer orbit by the mid-1980s, at a development cost of about $284 million. In order to achieve this, the mass of the first-stage propellant is increased 65 percent, and up to four boosters are added. Both the number of boosters and the type (solid or liquid) can be varied to match the launch vehicle to its payload. This is considerably more ambitious than the Ariane-4 originally proposed, which would have had a payload capacity of only 3,600 kg and would have used only solid rocket boosters. But studies indicated that the commercial satellites of the 1980s would be far heavier than originally believed, so Ariane-4's planners decided to include liquid-fuel boosters into its development program.

Schematic view of Arianes 1 through 5. Payload capacity for geosynchronous orbit is listed beneath each rocket.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Ariane-5 would lift substantially more than 10,000 kg into low Earth orbit (one-third the present payload capacity of the Space Shuttle) and 5,500 kg into transfer orbit. The first stage would be identical to that of Ariane-4, but the second stage would be new — although its cryogenic engine is already under development in France. Although Ariane-5's second stage is similar to the U.S. Centaur upper stage, it is far more advanced. The design is derived in part from studies done on a space tug before Europe decided on the Spacelab modular laboratory as its contribution to the Space Shuttle program. Ariane-5's cost per kilogram of orbited payload would be only 40 percent that of Ariane-1 — it could still be competitive with advanced versions of the Space Shuttle for many commercial payloads.

Ariane clearly has the potential to evolve into one of the most advanced launch vehicles in the world. But in order to fully utilize any advanced launch vehicle, it must have some place to go — ideally, some place capable of providing power, stability, communications, and other support to long-term payloads. If these services could be provided "on orbit," more of an individual payload's mass could be devoted to the equipment needed to fulfill its mission, and fewer copies of expensive support equipment would be necessary. Cumulative launch costs would thus be greatly reduced. Crews launched into space to repair malfunctioning satellites could further reduce duplication and allow a relaxation of expensive redundancy and reliability requirements. To address these problems, France is studying an automated space station called Solaris and a small space shuttle called Hermes.

Solaris evolved from the idea that Europe's forte in advanced technology is automation. Let the United States and Russia waste their money on expensive manned space stations — Europe would carry off the same coup it

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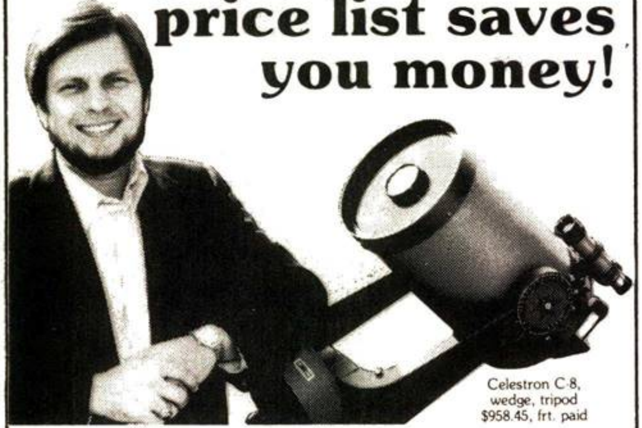

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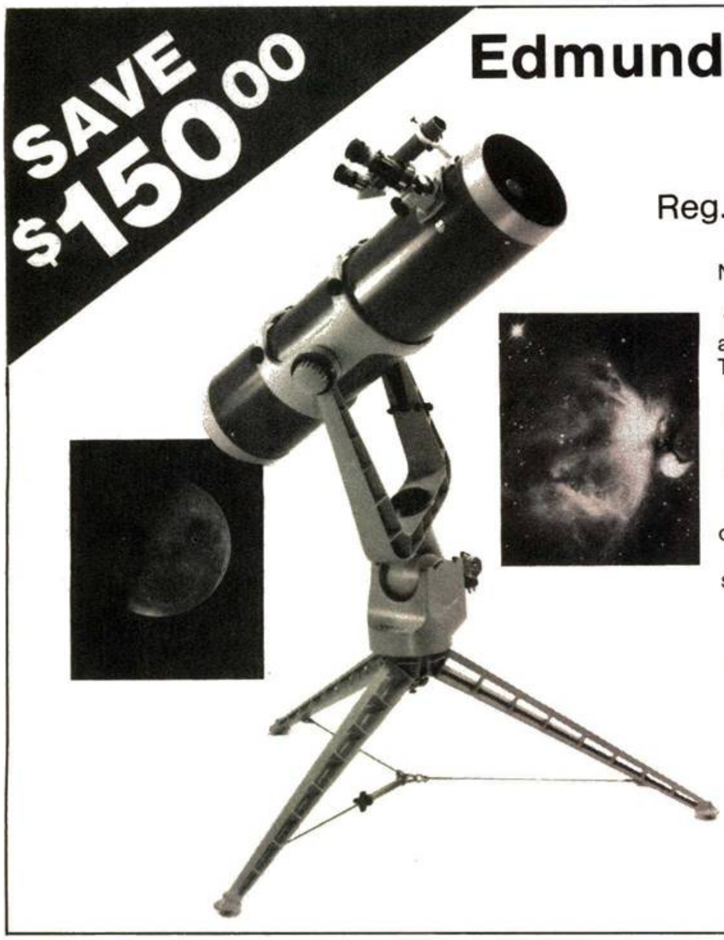

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is attempting with Ariane. It would develop a less capable — but far cheaper — system optimized for commercial applications.

Solaris would consist of a large automated platform placed in low Earth orbit by an Ariane-4 rocket in the mid-1980s. The platform would support a number of modular commercial payloads that might include: a high-performance synthetic-aperture radar similar to that flown on the second Space Shuttle mission; a payload that would process up to two tons of raw material into valuable products difficult or impossible to manufacture on Earth; a facility for the construction of satellites too large or too heavy to be launched as a single payload. Two geosynchronous relay satellites would allow continuous communications, and an automated shuttle similar to the reentry vehicle of an intercontinental ballistic missile would allow resupply and return to Earth of processed materials.

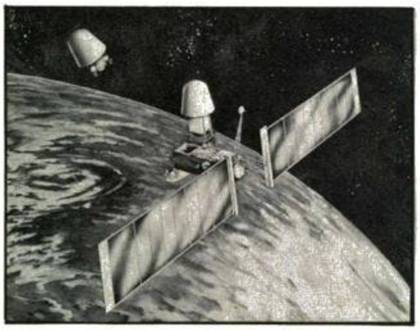
A typical mission might begin with the launch of an automated shuttle on an Ariane-4, which would then maneuver to rendezvous and dock with the space station. One of the station's four robot arms would carefully open the shuttle and remove a modular electronics assembly that will later plug into the radar to replace a malfunctioning unit. Then a load of new raw material for the processing furnace would be unpacked and set in storage. Finally, a part for a large communications satellite under construction by the station's other three arms would be transferred to the construction site. Later, the shuttle, filled with processed products, malfunctioning equipment, and waste, will undock to fly an automated reentry for ocean recovery.

Solaris would be a versatile machine capable of many of the functions anticipated for NASA's manned Space Operations Center, at a much reduced initial investment. Yet not all European technologists support this approach. Others argue that Europe should take advantage of its lead in manned space station technology, established with the development of Spacelab, to obtain a major part in any American space station program. They believe that Europe should concentrate its limited resources on improving the technology and utility of Spacelab.

But after looking closely at NASA's experience with the Space Shuttle, the European Space Agency is reluctant to begin any large long-term projects that could sap needed resources from its other, smaller, scientific programs. Interestingly, a stripped-down Spacelab might weigh as little as 10,000 kg, possibly even 5,000 kg. While no one has announced such plans, Europe has the potential to launch its own manned space station modules on the Ariane-5.

Still other technologists argue that Europe should now begin full-scale development of a small manned space shuttle that has been studied by French industry since April 1977. In its latest form, the Hermes space shuttle would weigh around 10,000 kg and ride atop the second stage of an Ariane-5. It will be largely reusable and will support a three-man crew for a seven-day mission. Further, this craft will be capable of moving a space station module from a 200-km orbit to a space station in a 400-km orbit and docking them together. Subsequently, Hermes will supply the completed space station.

On a typical flight, Hermes would be launched into a 200-km orbit where it would open a single door on its upper fuselage to expose its communications antennae, rendezvous and docking equipment, hatch, radiators, and experiments. After completing its mission, Hermes would reenter and fly to a landing in essentially the same manner as the U.S. Space Shuttle.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Solaris — an automated space station.

Hermes would probably use the most complex technology ever attempted in Europe — far surpassing the Anglo-French Concorde supersonic transport in both difficulty and expense. Thus the European Space Agency is even more reluctant to begin this program than they are to continue development of Spacelab.

Yet another argument against any European space shuttle is precisely the argument that was used in support of the U.S. Space Shuttle. Hermes has no well-defined use. Unlike the U.S. vehicle, it cannot deliver satellites into orbit. It would make an inefficient space tug to move space station modules about. The U.S. Space Shuttle can be hired for satellite repair (though there is a faction, especially in France, that does not want to rely on the United States for anything at all). In short, unlike Ariane, there is no way that Hermes can ever hope to compete with the U.S. Space Shuttle.

For all these reasons, I do not think it likely that Europe will begin development of a manned space shuttle in the near future. On the other hand, I suspect that the reluctance to end the Spacelab program will outweigh the reluctance to continue it. If the Spacelab program is extended, it could become the building block of any U.S. space station. Such cooperation can, I think, do nothing but good for all the countries involved — although American industry might not quite see it that way. Alternatively, Europe may decide to compete directly with any U.S. space station with Solaris. And, of course, Arianespace will continue to compete for launch services. Three U.S. companies — G.T.E. Satellite Corp., Western Union, and Southern Pacific Communications Co. — have already chosen to launch their satellites on Ariane rather than the Space Shuttle. The net result of all of this could be something of a contradiction: closer cooperation between NASA and the European Space Agency in pure research and development (although the Reagan administration's unilateral cancellation of the U.S. half of the International Solar Polar mission may do much to undermine this prospect), combined with greater competition for commercial services. France's growing cooperation with Russia in space, culminating in the flight of a French astronaut on a Russian Salyut space station in 1982, may or may not continue, depending mostly on the Russians. But with the development of Ariane, Spacelab, Solaris, and Hermes, Europe could develop the potential for a third course — a course increasingly advocated by the French, a course that Europe is financially capable of taking: bypass both the United States and the Soviet Union in space and ultimately instigate a resurgence of European civilization not seen since the Renaissance. The new renaissance would at first be based on the services provided by relatively inexpensive commercial space stations.

This is a prospect the Reagan administration should remember as it continues to advocate a redirection of United States space efforts toward large military systems at the expense of civilian and commercially oriented programs. We are used to looking to the Russians for competition in space, but competition can take many forms, not all of which are military.

Space is indeed no longer the exclusive realm of the superpowers. The prize may well go not to the biggest or the fastest, but to the most efficient.

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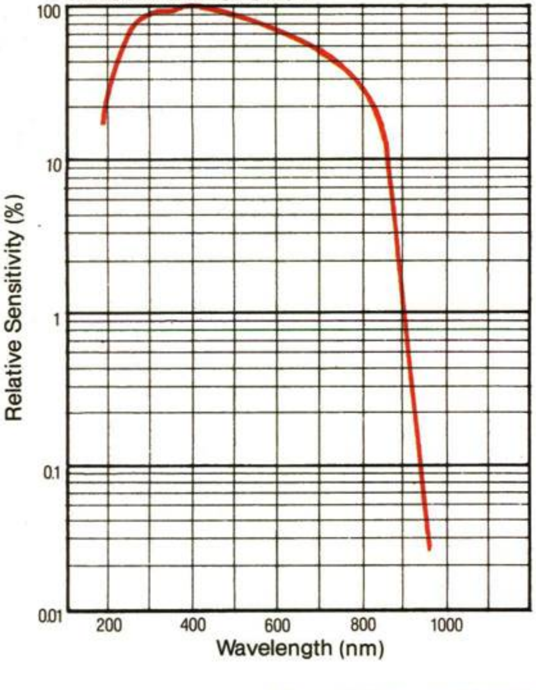

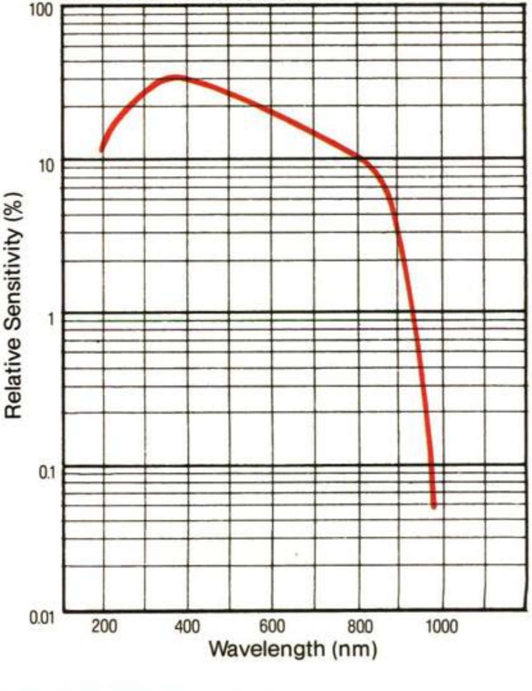

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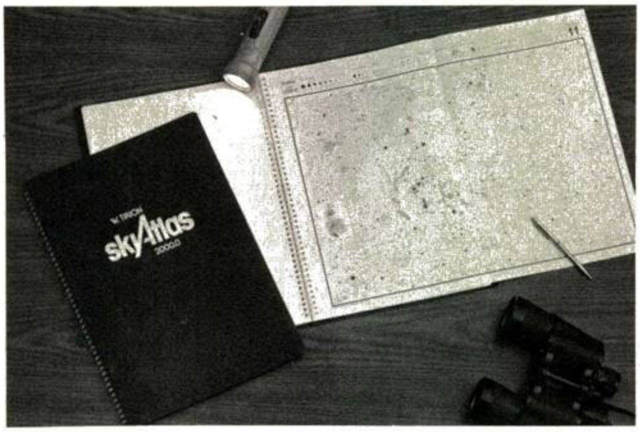
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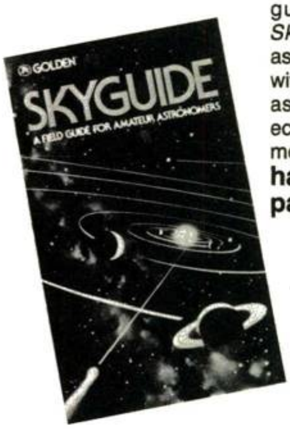
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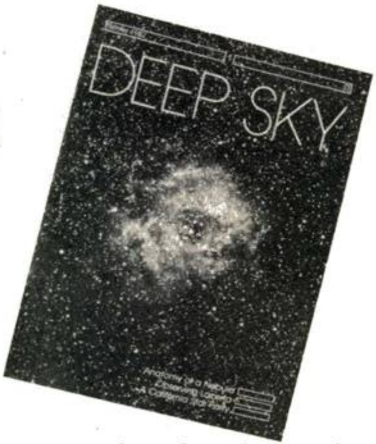

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Fall 1982
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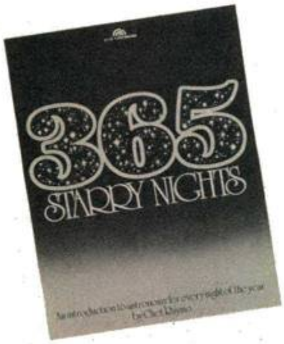
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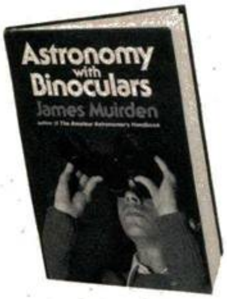
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James Muirden

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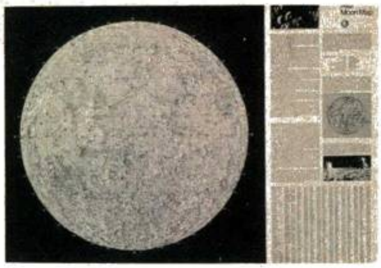

Through a telescope, the Moon looks like an immense anonymous jumble of craters, hills, and flat expanses. This 20" x 29" Moon Map will help you identify everything on the Moon you can see with your telescope. Includes an index to the Map and a description of the Moon's origin and surface features.

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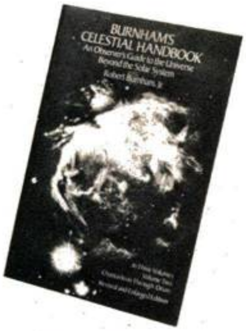
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IN FOCUS

Astronomy Day Giveaway

Sir / To help clubs and individuals publicize astronomy, Abrams Planetarium produces a monthly *Sky Calendar* showing what there is to see evening by evening in the sky. The *Sky Calendar* promotes skywatching for people of all ages.

It is currently received not only by its 6,000 subscribers, but also reproduced, with permission, by teachers for use in school classrooms and by planetariums and astronomy clubs for their members and the general public. The front side of the calendar, in a calendar format, invites the reader to track the Moon past the planets and bright stars of the zodiac. The reverse side consists of a simplified star map of the month's evening sky. A year's subscription costs $5.00.

This year, as a special service, we are making the April and May calendars — plus a complete, reproducible sky quiz — available to groups and individuals who would like to use them for Astronomy Day. The cost is $1.00 plus a long self-addressed envelope with 37 cents postage on it. The address is: Astronomy Day, Abrams Planetarium, Michigan State University, East Lansing, MI 48824. You can take these originals to your local quick printer and run as many copies as you need.

Robert C. Victor
Staff Astronomer
Abrams Planetarium

Knowledge *vs.* Welfare

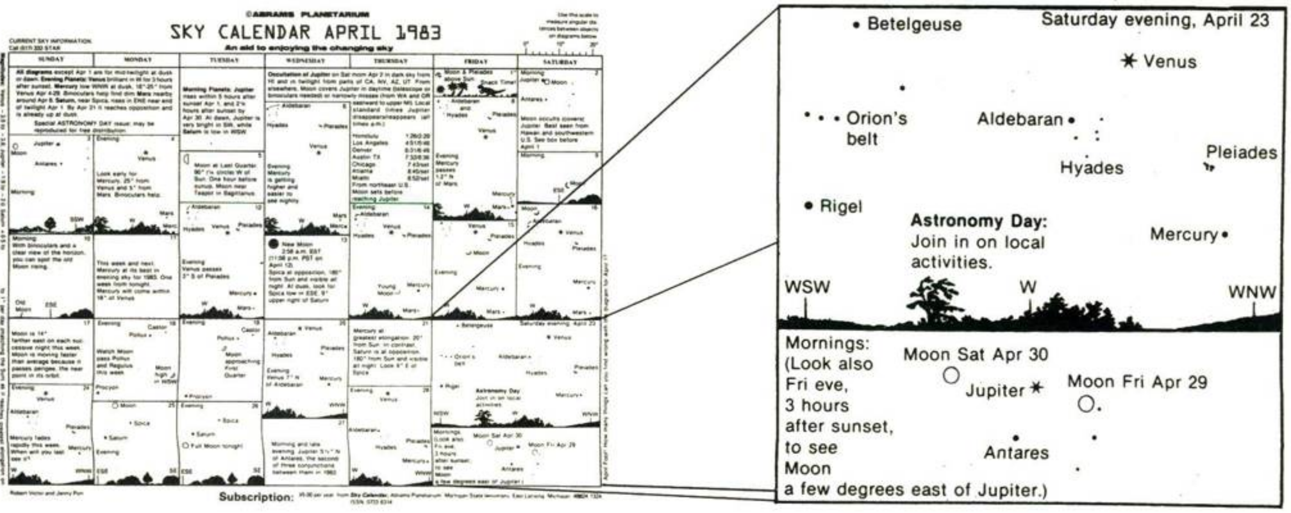
Sir / After looking at the January ASTRONOMY, I feel compelled to comment on statements made by Robert Becker in In Focus. Certainly funding for space research is dwindling. To claim otherwise would surely be foolish. However, to say that what is left should be channeled into more public assistance programs is downright asinine.

This is indeed a nation of "haves" and "have-nots." By and large, people who have things achieve them through the effort which they expend. Others are content to wallow along, contributing nothing to society, and nevertheless collect welfare checks. And there are the hard-core unemployed, who will not attempt any type of work and who will remain on assistance regardless of the situation. This very attitude has created multiple generations who live on but welfare. Only by examining each case of welfare can we weed out the truly needy from the "free-riders."

I'm sure that our defense could survive if we had fewer planes; however, our species has a paranoia about protecting ourselves from our enemies. It appears that this attitude, which has existed since the first stone was thrown, will persevere until the very end.

If we are to attempt to locate funding for more worthwhile projects,we should immediately look at several points: (1) foreign aid involves an enormous investment and very little return; (2) employment of a stiff import tax — try buying a Detroit automobile in Tokyo or Berlin! — would greatly help; and (3) goods sent to OPEC countries should parallel the price structure of their products.

The day of the "free ride" is rapidly coming to an end. Although Mr. Becker alleges that the space program's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An aid to enjoying the changing sky
SUNDAY
MONDAY
TUESDAY
WEDNESDAY
THURSDAY
FRIDAY
SATURDAY
Subscription:
• Betelgeuse
Saturday evening, April 23
Venus
• • • Orion's belt
Aldebaran •
Hyades
Pleiades
• Rigel
Astronomy Day:
Join in on local activities.
Mercury •
WSW
W
WNW
Mornings:
(Look also Fri eve, 3 hours after sunset, to see Moon a few degrees east of Jupiter.)
Moon Sat Apr 30
Jupiter
Moon Fri Apr 29
Antares

"well-fed people" are personally responsible for 200,000 others without roofs over their heads, he is dramatically oversimplifying reality. The fact is that all working people are tired of subsidizing those who, by choice, flatly refuse to better their situation. We do need drastic welfare reform; we do not need to undermine the philosophy or goals of science and human understanding.

W. Wideman Holm
Worcester, MA

P.S. If Mr. Becker dislikes ASTRONOMY so much, one would expect him to cancel his subscription and get a refund rather than letting it run out. His unwanted issues should go to someone who can appreciate more than just the pictures.

Solar System Chart

Sir / The Astronomical Society of the Pacific has prepared a chart of data on the planets and satellites in the solar system. The chart includes the latest information about the orbits and physical characteristics of each body.

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Cold-Camera Info

Sir/For my county science fair, I am doing a project on cold camera astrophotography. I've desperately tried to find information on why film speed increases and why color film layers stabilize at low temperatures, but haven't had any luck. I also need to know which films work best when cooled. Could you help me? I'm looking forward to hearing from you and wish you many warm nights of observing.

Blaine Korcel
Springfield, VA

— Chilling emulsions doesn't increase the speed of a film, but it partially arrests the reciprocity failure problem and allows low-level light to be recorded more efficiently. When color film is chilled, the reciprocity failure rates for the three layers of color equalize, making the color balance superior to unchilled film. Try some different fast emulsions with your cold camera to see which one works best with your system. If you want to know more about these cameras, read "A Cold Camera for Astrophotography" in the February 1981 issue of ASTRONOMY.

The Crab Supernova

Sir / In all the accounts I've read of the birth of the Crab Nebula, it seems that the only people to notice it were the Chinese. And yet it must have been bright enough to be noticed elsewhere — why not in Europe or the Americas?

R. W. Long
West Palm Beach, FL

— That's a question that many astronomers have wondered about, too. One suggested answer is that the weather over Europe was generally so poor during the time when the supernova was at maximum brightness that nobody noticed anything unusual — but this reply seems a little glib. It is far more likely that Europeans did notice the supernova, but were prevented from recognizing it by the prevailing attitudes concerning the "immutable" heavens. Aristotle had said that the skies were unchanging and perfect, and many seem to have taken him at his word. As to the Americas, archaeologists have unearthed several pictographs that might refer to the event, but in no case is the evidence conclusive.

Ooops!

We got the wrong star — the light curve shown in "Backyard Photoelectric Photometry" (ASTRONOMY, February 1983) is for 44 Bootis, which is also named i Bootis; hence the error.

Vanderbilt University is not in North Carolina, as was stated on page 71 of the February '83 issue, but in Nashville, Tennessee.

behind the scenes

signs of hope

NASA's failing planetary program shows some signs of emerging from the 1981 to 1986 planetary hiatus not exactly vigorous and strong, but at least not dead. With Voyager 2 on its way to Uranus and Neptune (see page 6), and the Galileo mission to Jupiter still on the books, now is a good time to ask what's next. NASA wants to make a new start on the Venus Radar Mapper (see page 16) in Fiscal Year 1984, but whether any new mission can survive the budget crunches coming in the next few years is doubtful.

Although the byword in mission planning is now "cheap," space exploration still doesn't seem to rank high on the list of national priorities for most Americans. Once again, now is the time to be writing to your senators and representatives in support of space if you want to see it supported.

However, it is pleasing to see that if the United States doesn't do it, other nations will. We plan to tell you about the Japanese, Russian, and European missions to Comet Halley in an upcoming issue. Though ESA's Ariane rocket has had its troubles, Europe's ambitions in space (see page 24) are not modest. Certainly the Dutch are proud of their role in IRAS (see page 66) — prouder, I suspect, than the average American is of the Space Shuttle.

Well, aside from writing letters, what can you do? One very important activity tends to get overlooked — and that's getting outside and getting other people to look up at the sky. You don't even need a telescope. December's lunar eclipse, the quintessential non-telescopic event, seems to have attracted a lot of media attention.

How many little kids (and big kids) caught the astronomy bug by secretly waking up in the wee hours and watching the Moon disappear into the Earth's shadow? It was a lunar eclipse — a bright, copper-colored Moon watched through a window on a cold March morning — that years ago got me actively interested in learning more about astronomy.

This year, set aside a few hours to show other people a little bit about astronomy. One excellent date is April 23, Astronomy Day. If you belong to a club, help them show off telescopes and star pictures in a shopping mall or set up telescopes in a city park for public star-viewing sessions. If you observe by yourself, set up in your front yard. Invite some people over. Show them the stars.

Sincerely,

Richard Berry

Richard Berry
Editor

ASTRONOMY's
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The Starry Sky poster blends the beauty of the heavens with the history of astronomy.

The full-year version of ASTRONOMY's monthly Star Dome, the Starry Sky poster shows the entire northern sky at once — 6500 stars, plus galaxies, planetary nebulae, Messier objects, and the bright path of the Milky Way. Constellations are outlined for easy identification.

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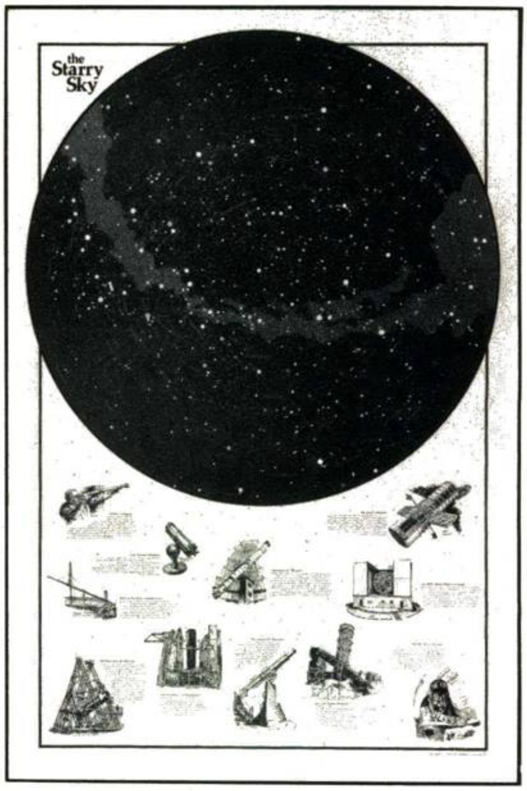

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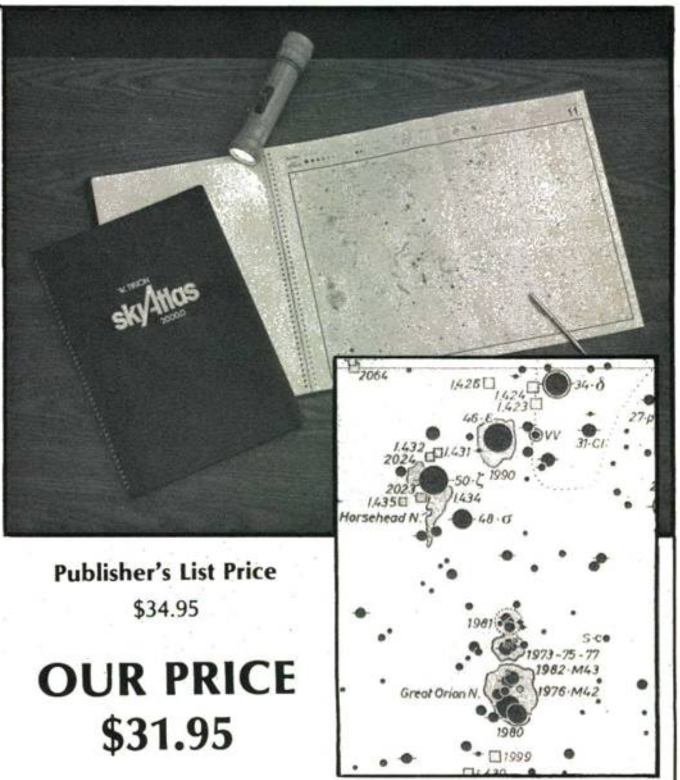

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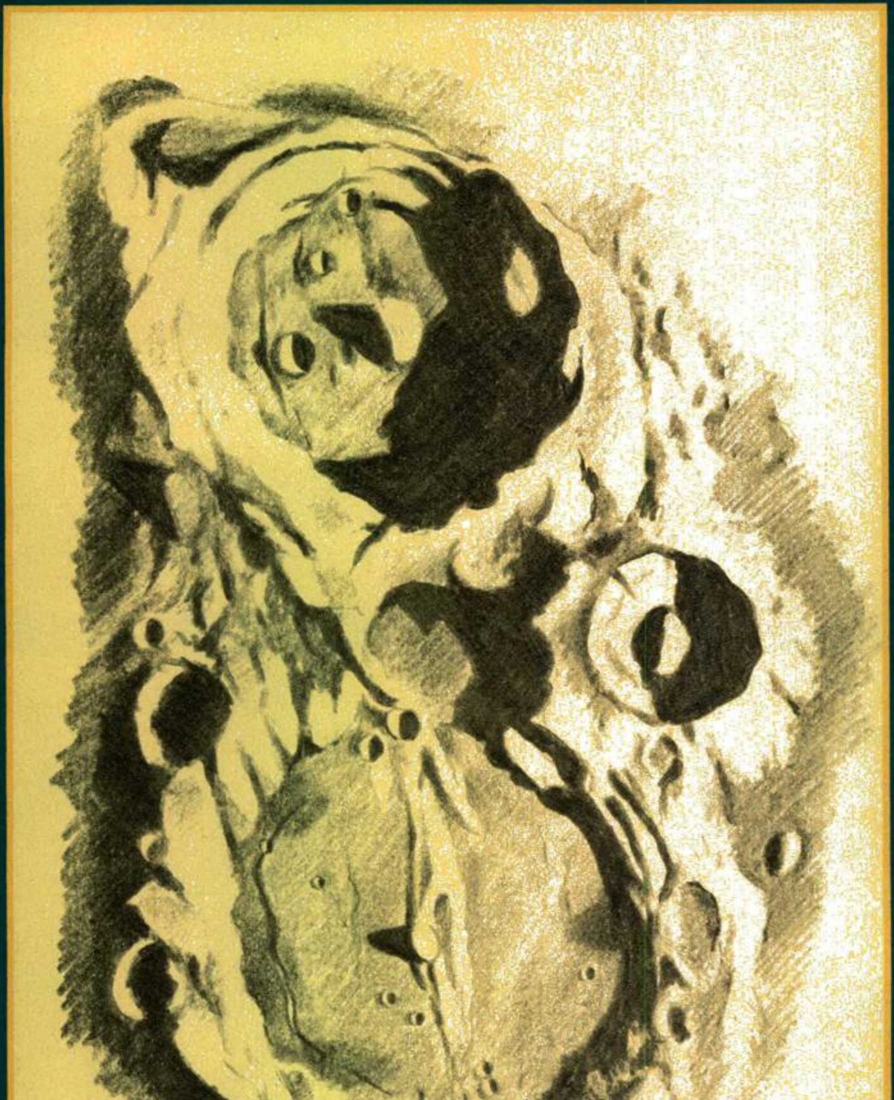
sketching the moon and planets



It's late evening. For the past few hours, you've been observing and sketching galaxies in Virgo and Coma. But a short while ago, a very thin haze started drifting in, and it now covers most of the sky. The seeing is still good — improved a bit, in fact — but the haze has picked up a glow from the rising Moon, a few days past Full. Deep-sky observing is over for tonight.

But before you pack away your gear, you swing the scope over to the Moon. Wow! There it is — craters, rays, mountains, plains. You'd forgotten how impressive the Moon is. Suddenly, a sneaky notion crosses your mind. Why not have a go at sketching the Moon, too?

Nah! There's too much of it — and, cripes, it's as complicated as 23 Lagoon Nebulas all put together! But it sure looks nifty — and the seeing's as steady as you could ever wish for. . . .

Sketching the Moon *is* a lot more difficult than sketching most deep-sky objects — and the planets are no cinch either. You're going to need patience and practice, but it's certainly worthwhile: just as with deep-sky objects, you'll come away with an increased awareness of these celestial bodies, a new appreciation for their beauty, and — almost incidentally — a permanent record of your observations. To begin, the equipment is the same as for sketching galaxies or nebulae: an Ebony pencil, an eraser, good paper, and a dim red light to work by. You can get into the accessories later. (See "Capturing Deep-Sky Objects on Paper," ASTRONOMY, February 1983.)

The Moon: With Luna, your biggest problem is the overwhelming detail your eyepiece presents. So to keep things manageable, concentrate on a small

Mark Daniels used an 8-inch Newtonian at 180x to sketch the craters Arzachel, Alpetragius, and Alphonsus as they were lit by the afternoon Sun. Note the variations of color on the floor of Alphonsus (bottom) and the unusually large central peak in the small crater Alpetragius (center right).

region or, ideally, on a single feature. For instance, if you ignore its surroundings, even a complex structure like Copernicus can be depicted fairly quickly.

Work the way the early selenographers did: pick three or four prominent points (peaks or small craters) that surround the feature and get them down on paper accurately. There's no hurry — time spent here will be amply repaid. Then place a network of secondary control points based on the main ones. When you have finished, you will have a rough grid to help you draw in the intervening terrain.

Proceed slowly, and consider it a triumph if you come away from the telescope with a single sketch that's recognizable. Later the same evening or soon after, rework it into a permanent version that has a little more polish. Finish it off by noting the scope and eyepieces used, observing conditions, and date. (But no looking at photos — that's cheating!)

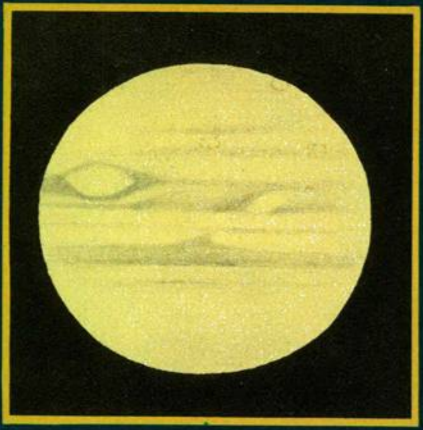
The Planets: Sketching planets is different from doing the Moon. Instead of capturing a welter of detail, you will be trying to see and record a few very subtle features. Among the planets, only Mars, Jupiter, and Saturn offer much detail on their disks: Mercury and Venus essentially have none, the outer gas-giants are too far away, and Pluto has no visible disk anyway. But don't worry — you'll find plenty to see and record on these three as it is.

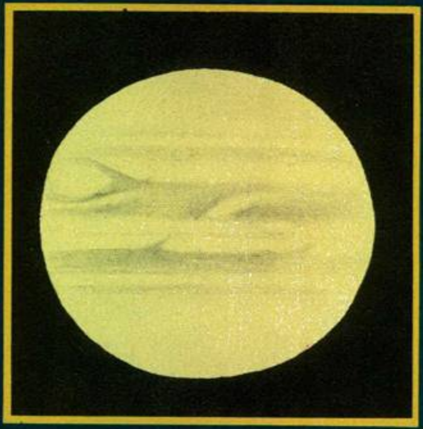
To sketch Jupiter, start by tracing a blank disk with a 70° ellipse template (bought in an art supply store), or use the outline diagram in Backyard Astronomer as a guide. Keep it small — one and a half to three inches across is best. Bigger than that and you'll be tempted to put down details you aren't really seeing. Work quickly on Jupiter — 10 to 20 minutes maximum per sketch. When you've accumulated some practice, rough in the equatorial belts lightly before you start, then amend them at the eyepiece to fit what you see.

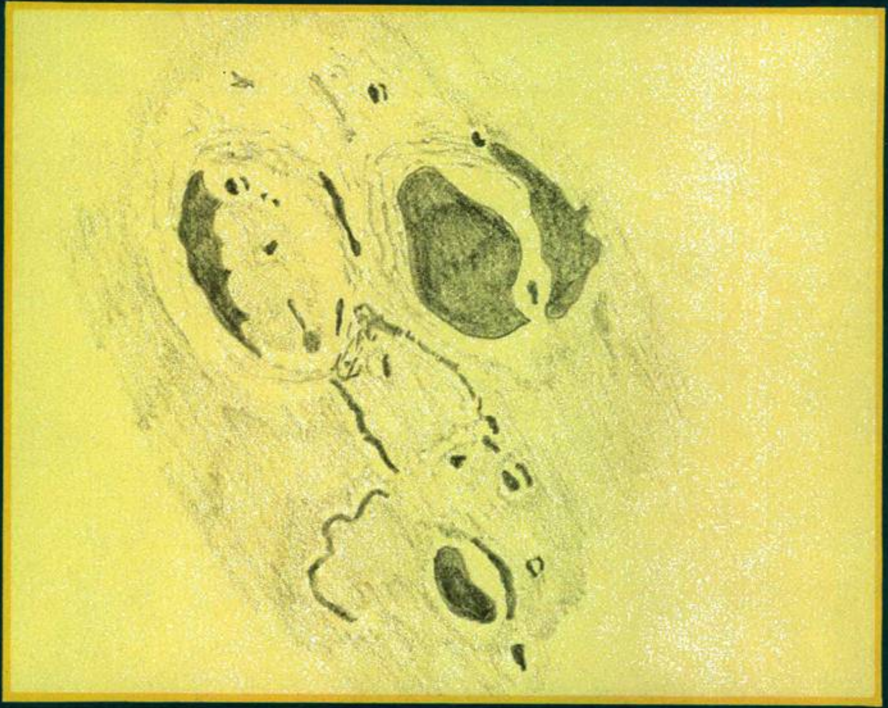
With Saturn, making a blank calls for a multitude of templates to match the changing aspects of the planet and rings — your best bet may be to use the outline in Backyard Astronomer. Saturn also rotates quickly, so work fast with it.

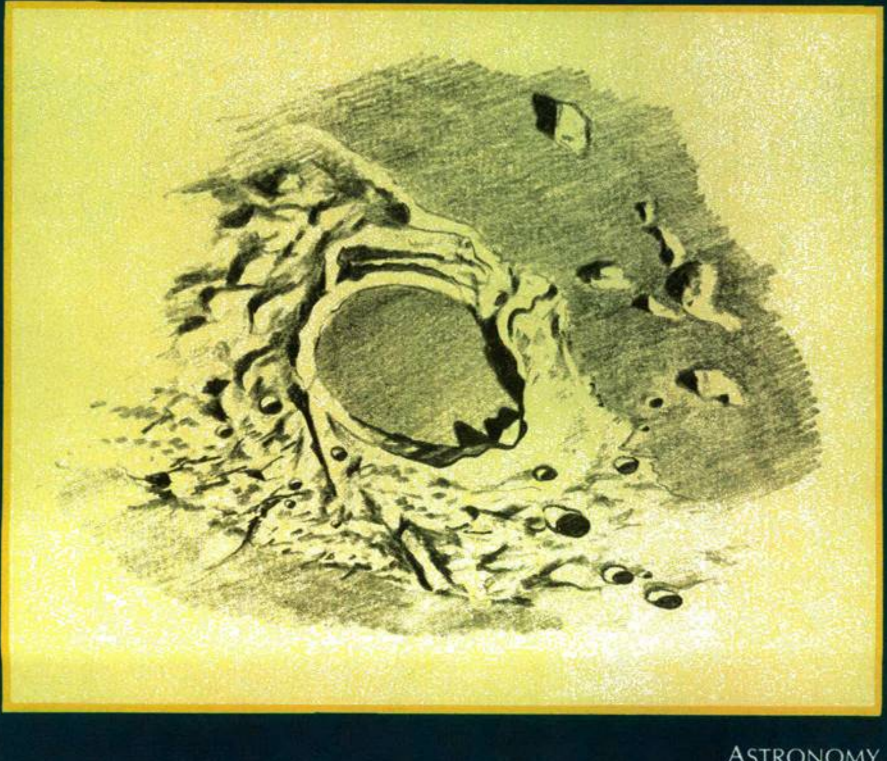
Mars presents different problems — its markings are fairly distinct, but the planet is so small that only the coarsest show clearly. However, as with Jupiter and Saturn, practice will help you discern more. An accurate sketch of Mars should also note the planet's phases. Around eight weeks before and after opposition, the planet shows a distinctly gibbous shape; sketches that ignore this aren't accurate. As a guide, refer to the outline in Backyard Astronomer.

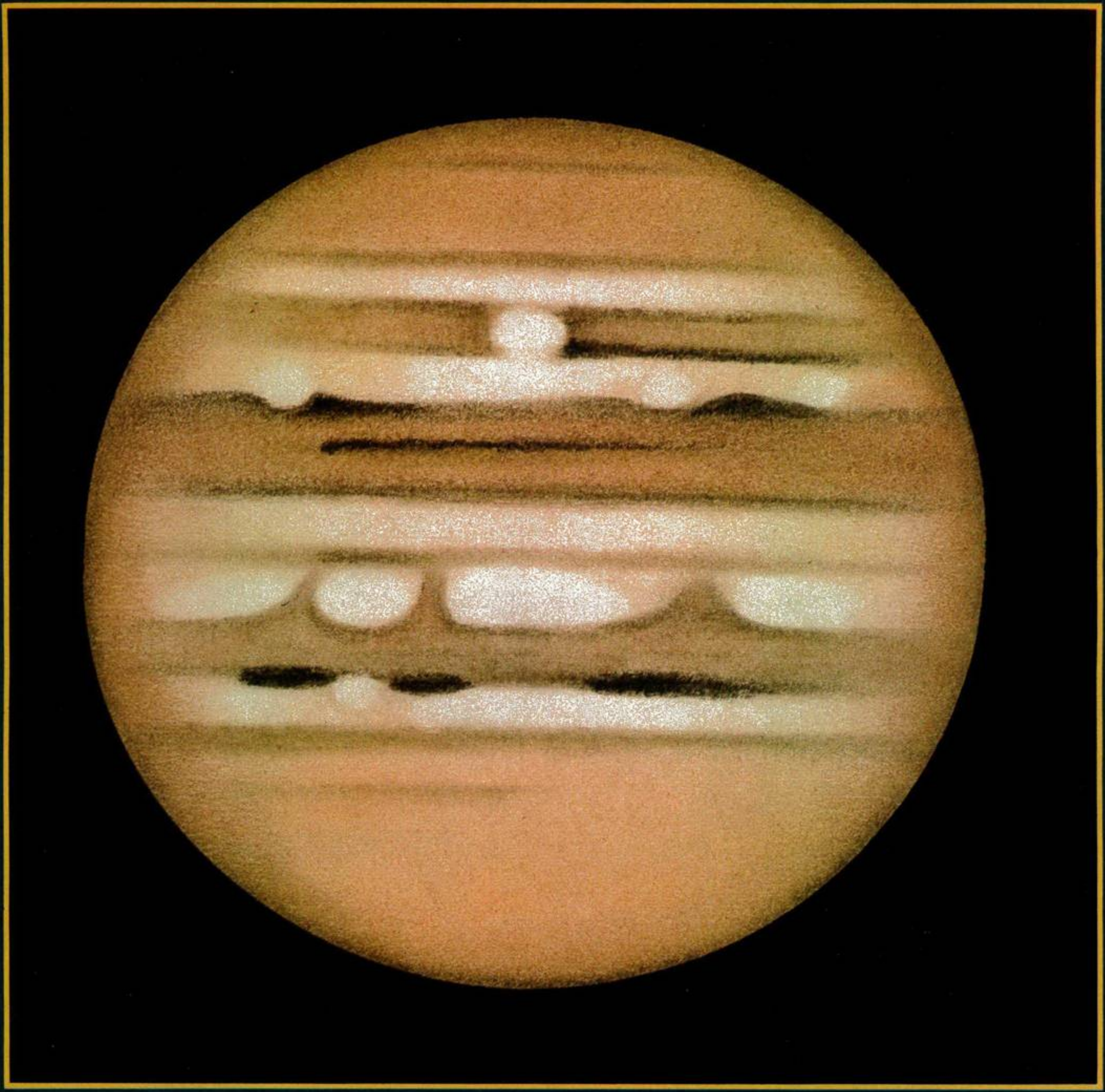
Comets: Getting a comet's image down on paper is really more like sketching deep-sky objects than solar system ones. Start by placing a few stellar reference points and then lightly work in a grey spot where the comet is. Smudge the grey area into a smooth tone and add any coma

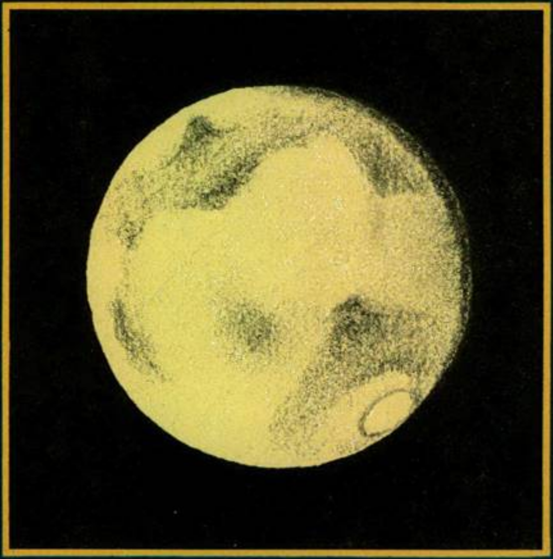










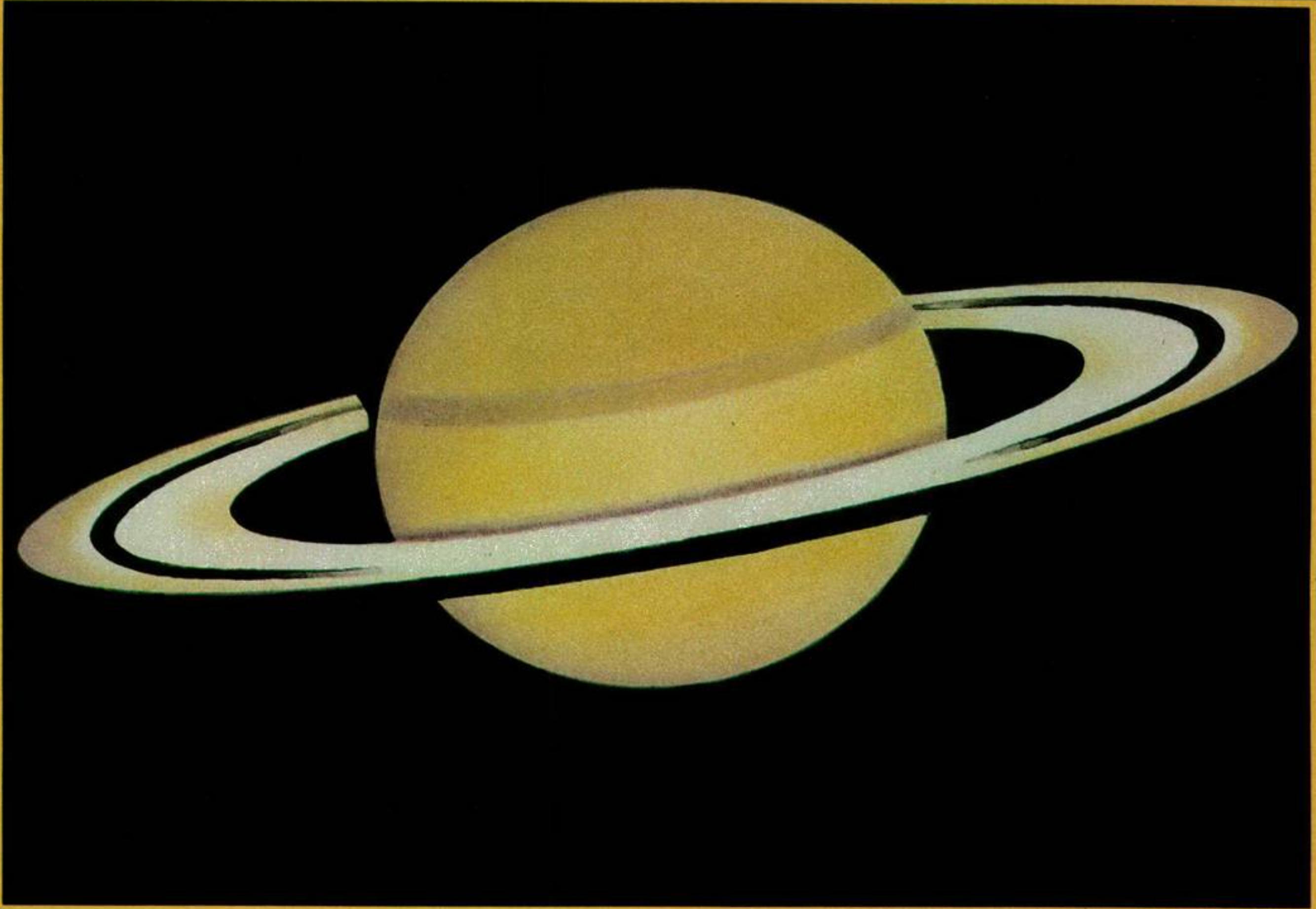


Clockwise from bottom left: Mark Daniels did this sketch of Plato and the Teneriffe Mountains on Mare Imbrium. He used an 8-inch Newtonian and 220x.

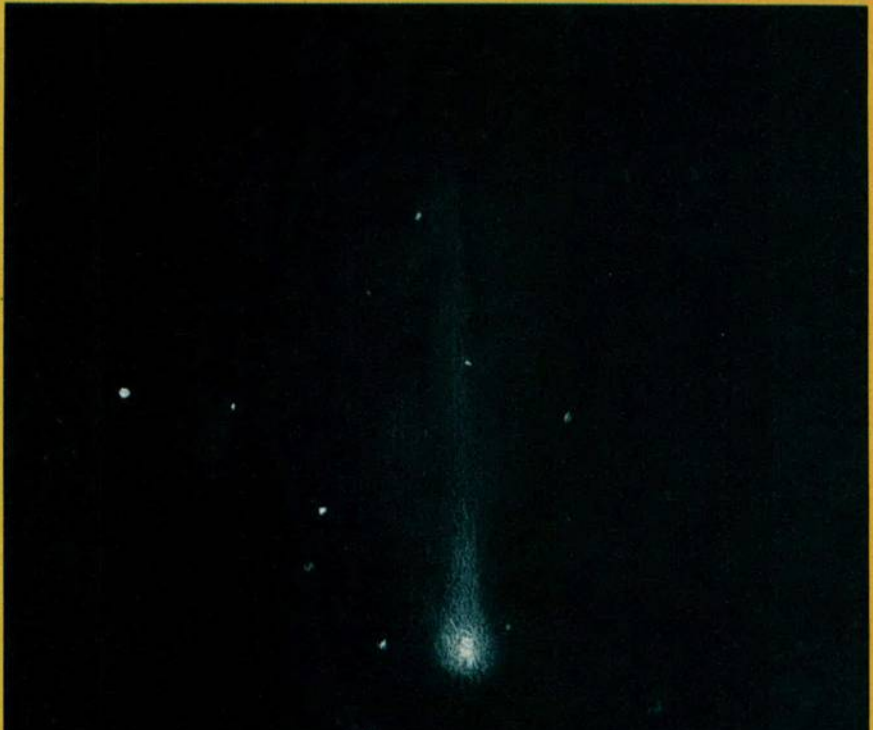
Philip W. Masding observed the craters Altas and Hercules soon after lunar sunrise; he used a 6-inch Newtonian at 220x.

These three views of Jupiter — two drawn at the eyepiece and one finished in color — were done by Mark Daniels. The two little sketches (at top left) were made 15 minutes apart; Jupiter's rotation is evident. The finished sketch (above) was based on observations made during another night.

Although the night's seeing was only moderately good, Mark Daniels noted that details of martian surface markings were well defined. The central meridian in the sketch (right) was 257°, that of Mare Cimmerium.



Above: A color sketch of Saturn by Mark Daniels. Right: Jan Romer varied the ordinary method by using a white pastel pencil on black paper for her drawing of Comet Austin. Her telescope was an 8-inch Newtonian, and the power she observed with for making the sketch was 50x.



details that are visible. For an alternate approach, try black paper and white pastel pencil.

Some general hints: First, ink around the disk blanks so they match the eyepiece appearance more closely. Work lightly; build up "color" slowly. (Except with the Moon, your sketches will unavoidably have more contrast than the real thing; just don't let it get out of hand.) Use colored filters — red, blue, green, and yellow — to enhance detail when you observe. To depict natural colors, use pastel pencils — but go easy, a little is almost too much.

...It's now well into the wee hours. Your back is killing you, your eyes are blurry, fingers have grown cold and stiff. As you pack up your things, including four lunar sketches and two of Saturn, you glance to the southeast — there's Jupiter. You look at it, then at your scope, and finally at your watch. You stifle a groan — and call it quits. After all, Jupiter *will* be there tomorrow night.

— Robert Burnham

ASTRONOMY
REVIEWS

Celestial BASIC: Astronomy on Your Computer
Eric Burgess
288 pages, paperback, $13.95
Sybex (1982)

This appears to be the first of what I hope will be a whole genre of books on computer programs for amateur astronomers. It contains 23 programs that do calendar and time conversions, compute precession, determine planet positions, predict eclipses, and even plot the constellations on the screen with the planets in place. The big advantage of using a computer rather than looking up the values in the *Astronomical Almanac* is that the computer customizes the results for your own latitude, longitude, and time zone with no special effort on your part. While there are other computations that I'd like to see programs for (the inclination of Saturn's rings, for instance), the ones in this book are certainly versatile enough to satisfy most observers' computing needs.

But there are two problems. The first is that there is very little discussion of how the calculations are actually done. It would be a great help for many users to see the actual formulae — if only to check their understanding of the programs. The other problem, considerably more serious, is that the programs are written in Apple II BASIC and — despite the author's occasional remarks to the contrary — are not easily adaptable to other machines.

The programs make extensive use of features peculiar to the Apple, but the book does not give a full account of the Apple's peculiarities. For example, the author assumes you know that the VAL function returns zero on a non-numeric argument and that if other statements appear on the same line as an IF, all of them — and not just the one in the THEN clause — are conditional. Statements like FLASH and VTAB, which are utterly unintelligible in any other dialect of BASIC, are not explained anywhere. To translate the programs into your version of BASIC, you'll need a thorough book on Apple BASIC. This will tell you what the non-standard commands do, and you may then be able to write routines to get the same result on your machine.

In sum: If you have an Apple II and don't mind typing in pages of code, this is the book for you — you're getting what could be several hundred dollars worth of software for $13.95. But if your computer is another brand, be prepared to tackle what might turn out to be a large conversion job. You could well end up working the programs over almost to the same extent as if you were writing them from scratch. *Michael A. Covington.*

Space
James A. Michener
624 pages, hardcover, $17.95
Random House (1982)

This novel is pop-schlock writing at its most obvious — and I enjoyed all of it. It is ephemeral entertainment rather than lasting literature, hokey prime-time fare in words rather than TV images, yet I had great difficulty putting it down each evening. You can hardly distinguish one character from another, and the plot clumps along like a sack of hardened cement — but I'm no literary snob, so I loved every minute. The novel constantly sermonizes about the space program, and I was shouting "Amen!" and "Hallelujah!" throughout.

If you have the slightest interest in space exploration or if you enjoy a "fast read," you will want to read it. And if you like both, you will relish the virtual feast that this huge tome offers the astronomy buff and the pop novel fan. (And there must be a gigantic globular cluster of us, because as I write, the novel is #1 on the best-seller lists.)

Written by the well-known author of *Hawaii, Tales of the South Pacific, The Source, The Covenant*, etc., etc., *Space* is a fictionalized account of America's role in both manned and unmanned space exploration. It begins in the 1940s during the latter stages of World War II, when Russia and America were secretly struggling to grab the best of the incredible rocket scientists at Peenemuende — the people who built the A-4, the world's first production rocket, which Londoners knew so well and so horribly. The novel ends with this past summer's Space Shuttle flight, and with Michener's excited but sober speculations about future space travel and possible communication with beings from planets around other stars than our own.

The long novel is half over before the first American gets into orbit — a surprise, perhaps, but appropriate, considering how pathetically faltering the U.S. commitment to space flight was until the Russians got there first. Michener covers this period well by following the fortunes of four couples — a German rocket engineer and his down-to-earth wife who come to the U.S., an astronaut and his politically ambitious spouse, a war hero turned U.S. senator who's married to a bubblehead, and a clever administrator hustling the space program to the neglect of his family. The long, frustrating push and pull of those pre-Sputnik days is counterpointed by the stories of these and other characters.

Of particular interest to us astronomers is that the astronaut, a four-square John Glenn type, is also an astronomer, and therefore many pages are devoted to his education in astronomy as a boy, student, and adult. His favorite star is Altair, the bright star in Aquila the Eagle. The NASA administrator is also interested in astronomy, and *his* special emblem is NGC-4565, the spectacular edge-on spiral galaxy in Coma Berenices.

In really great literature, astronomical descriptions and references are frequently accurate, but this is seldom the case either in pop novels or in "serious" academic ones. So I found it quite a delight to come across consistently correct portrayals of what the Sun, the Moon, the planets, and the stars were doing while the characters were engaged in their activities. By day or night, when I'm out driving around, I notice what's in the sky — and so do Michener's people.

Once America's space program finally gets underway in the 60s, an additional group of figures appears, including a set of six astronauts, a couple of spacey senators, a likeably sleazy PR man, a sexy female Korean journalist, and a high-class con artist who gloms on to UFOs as his "snake oil."

A fictional Gemini 13 flight occurs, and then the still-slightly-unbelievable, real manned landings on the Moon follow — though Michener reminds us that the Russians "got there first, landed first, got samples first, and photographed the far side first." A fictional Apollo 18 moonflight provides the curiously unsuspenseful climax of the novel in the 70s. But the details of a landing on the far side of the Moon — complete with communications satellites in lunar orbit maintaining radio contact with Houston during the stay on the Moon's surface — are clever and well worked out. The climax itself involves lethal radiation caused by a gigantic solar flare.

The book concludes by winding up the stories of half a dozen characters and by describing the Voyager flybys of Jupiter and Saturn and the Shuttle flights. There's also a realistically grim coda in which Michener surveys the future prospects for American space science and exploration, including planetary and nearby stellar missions. We *could* do it all, you know — John Young was quite correct when he said, after deplaning from *Columbia*'s maiden flight, "We're really not too far — the human race isn't — from going to the stars." Michener (and I) doubt, however, that we Americans *will* do it.

The last pages of the novel discuss the question of communication with extraterrestrial beings, and the chart on page 612 should sober up a lot of fuzzy-minded speculation on that topic. No SF hyper-drives or time-warps are going to change the fact of sheer distance. Nor will any discussion that assumes that other technologically advanced species are as rapacious and as uncontrollably committed to cancerous growth as we are — a mistake even Michener makes — be reliable in estimating the chances of success of such a search for other beings.

Another major element recurring through the book is Michener's frequent, lengthy, and apposite observations on Americans' preoccupation with childish religiosity. The novel's successful "UFO doctor" later becomes an equally successful evangelist, to good satiric effect. It's about time some of Voltaire's grown-up attitude toward religion was applied to American mush-headed gullibility, and Michener's presentation is quite in keeping with the novel's other concerns.

But I must reiterate: this is not a tract — it's an engrossing book whose plot line is merely a coathanger on which to present the real story, neatly summed up in the title, "Space." It's the first attempt in fiction to do for the space program what Norman Mailer and Tom Wolfe have done for it in non-fiction — though it isn't of the literary caliber of their books. For all that, we can still have plenty of very enjoyable pop entertainment from Michener's delightfully unabashed novel of ideas. *John Mood.*

High Precision Earth Rotation and Earth-Moon Dynamics: Lunar and Related Observations

O. Calame, ed.
350 pages, hardcover, $54.50
D. Reidel (1982)

The dynamics of the Earth-Moon system, in which there are strong interactions between orbital, rotational, and deformational motions, has provided many clues to our understanding of solar system physics and astronomy. The study of the rotation of the Earth represents a major interface between astronomy and geophysics. Geared to professional astronomers, this book presents the latest results in theory and observation of Earth-Moon dynamics, including relativistic effects and terrestrial rotation parameters by lunar ranging (bouncing laser beams off the Moon).

Symposium on the Orion Nebula to Honor Henry Draper

Annals of the New York Academy of Sciences, Volume 395
A.E. Glassgold, P.J. Huggins, and E.L. Schucking, eds.
338 pages, paperback, $65.00
New York Academy of Sciences (1982)

In 1880, Henry Draper took the first photograph of the Orion Nebula. A century later, astronomers are just beginning to understand the complex processes that accompany star birth in this region. This book contains papers delivered at a symposium held in New York in December 1981 and includes discussions of the nebula and its large-scale environment, star formation in Orion, and observations of high-velocity molecular outflows. The book concludes with a brief section called "Henry Draper and His Legacy," which includes an essay on his role in the birth of American astrophysics. The book is typeset — a rarity in symposium volumes — and the photographs are reproduced fairly well.

While the book is designed for a professional audience, it contains a great deal of information of interest to amateur and armchair astronomers. Since this volume is a compilation of astronomical papers, much of it is only comprehensible to readers familiar with physical and chemical jargon. But substantial portions of the book are written at the level of *Scientific American*, and would probably

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be of interest to a number of non-specialist readers. Unfortunately, the New York Academy of Sciences has priced the book right out of this market. At one-third its present cost, the book would at least be affordable. Given the great interest in the Orion Nebula, it is hard to believe that the Academy would have lost money.

Anyone really interested in the violent processes of star formation should look for this volume in a library — but you may have trouble finding it. Only large public libraries will be able to afford this book. Since the odds are good that your local library won't purchase a copy, your best bet is to try a large university library. *Francis Reddy.*

Compendium in Astronomy
E. G. Mariolopoulos, P. S. Theocaris, L.N. Mavrides, eds.
466 pages, hardcover, $49.50
D. Reidel (1982)

This volume contains 36 essays on a wide range of topics in astronomy, astrophysics, optics, and space research. The exploration of Mars and Jupiter by the Viking and Voyager spacecraft, the physics of black holes, extraterrestrial intelligence, and optical systems for spacecraft are included in this diverse collection of papers.

Nebuleuses et Galaxies;
Atlas du Ciel Profond
Serge Brunier
191 pages, paperback, no price given
Dunod (1981)

This French guide to observing deep-sky objects features a list of objects by constellation, short summaries of the visual appearances of certain objects, and French amateurs' photographs of certain clusters, nebulae, and galaxies. The book includes a good cross-section of objects — not all bright ones — and should challenge deep-sky observers who know the native language of that famous comet hunter, Charles Messier.

Molecules in Interstellar Space
A. Carrington and D.A. Ramsay, eds.
631 pages, hardcover, £20
Royal Society of London (1982)

Research into the dust and gas that make up the interstellar medium has made great progress in the past few years. This book contains papers delivered at a Discussion Meeting of the Royal Society in May 1981. The topics considered are microwave and infrared observations, interstellar chemistry, laboratory observations, interstellar process, and the possible impact of cosmochemistry on terrestrial biology.

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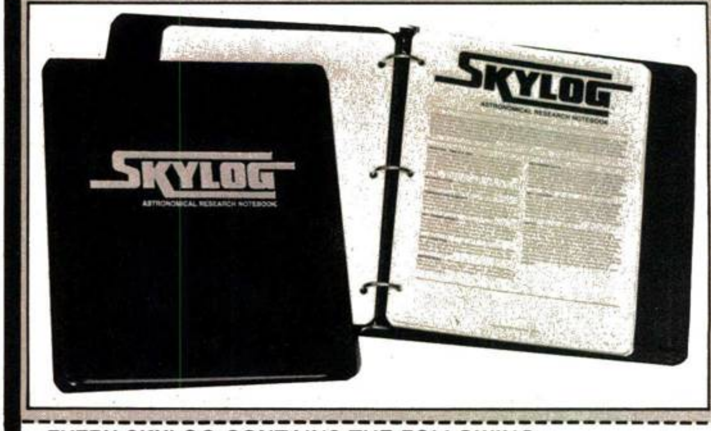

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eye on the sky

the moon occults jupiter

by Fred Schaaf

the wanderers

The spring of 1983 offers a superb opportunity to view the bright planets. Save for Mars — relatively dim all year — and Neptune, the best evening appearances of all the planets occur in April and May. In particular, the night of April 21 offers the best appearances of Mercury and Saturn; Jupiter and Uranus are at opposition just a month later.

Mercury reaches greatest eastern elongation on the 21st, when it is only 20° from the Sun. This is far less than the maximum possible, but the planet still offers a fine show. Forty-five minutes after sunset, it will float a full 11° above the horizon for observers at 40° north latitude; it is the best apparition of Mercury during the entire year.

In fact, this apparition of Mercury is the only time in 1983 when we can see the planet setting after evening twilight. Mercury will be detectable about April 9 and easily accessible a week later. It will remain bright and well placed for the rest of the month and will then fade as May approaches. Take note of Mercury's color, and keep an eye on its magnitude. It will dim from magnitude -1.5 to +1.0 as the month ends.

The other prime object in April is **Saturn**, which comes to opposition on April 21. As Mercury sets and twilight ends, Saturn rises in the southeast, pursuing the bright star Spica. The ringed planet moves westward this month in relation to the stars of eastern Virgo, but its retrograde loop is not very large because it is so distant — still 8.77 AU (astronomical units) away. Saturn begins the month close to dim stars 95 and 96 Virginis, and not far from fourth-magnitude Kappa (κ) Virginis.

Saturn is brightest on April 22, when it shines at magnitude +0.4 — about the same as Procyon, which is low in the west as Saturn rises. The planet is now more comparable to Arcturus than to Spica. Even though Saturn is moving toward the aphelion point of its orbit, each of its oppositions is brighter than the preceding one because the rings are "opening up" and reflecting more light toward us. This effect is so important that Saturn will display brighter and brighter oppositions until 1988.

April 21 is certainly the best date to observe Saturn and Mercury, but it is more difficult to specify a single date for the planet which outshines them both. **Venus** remains an excellent sight for the next several months, but it is perhaps best for most North American and British viewers in late April and May.

Even though Venus is farthest from the Sun in mid-June, it is at its highest altitude above the western horizon in May. During April the altitude increases significantly, so that it is only a degree or two short of its maximum value for most of us by May Day. On that date, Venus sets well over three hours after sundown and is a spectacular magnitude -3.6 light in Taurus at 40° elongation from the Sun.

Mercury, Saturn and Venus are all superb this month — but what about **Jupiter**? Jupiter's big event will be its occultation by the Moon on the morning of April 2nd. The Moon will be about three-quarters lit and waning; unfortunately for viewers, it will also be setting. Most people watching from the East Coast will be out of luck, but those in the southern states will be able to catch Jupiter's disappearance before the pair dips below the horizon. Across the continent the viewing improves somewhat, with the West Coast — and southern California in particular — being favored. But the big drawback is sunrise: only those in the west and southwest will see the occultation before the Sun comes up — and even then, the timing is close since the events occur after morning twilight is well under way.

Now moving slowly retrograde, Jupiter again approaches the star Omega (ω) Ophiuchi and also-retrograding Uranus. By month's end, -2.0 magnitude Jupiter rises little more than two hours after sunset and can be compared with Venus, almost directly opposite it.

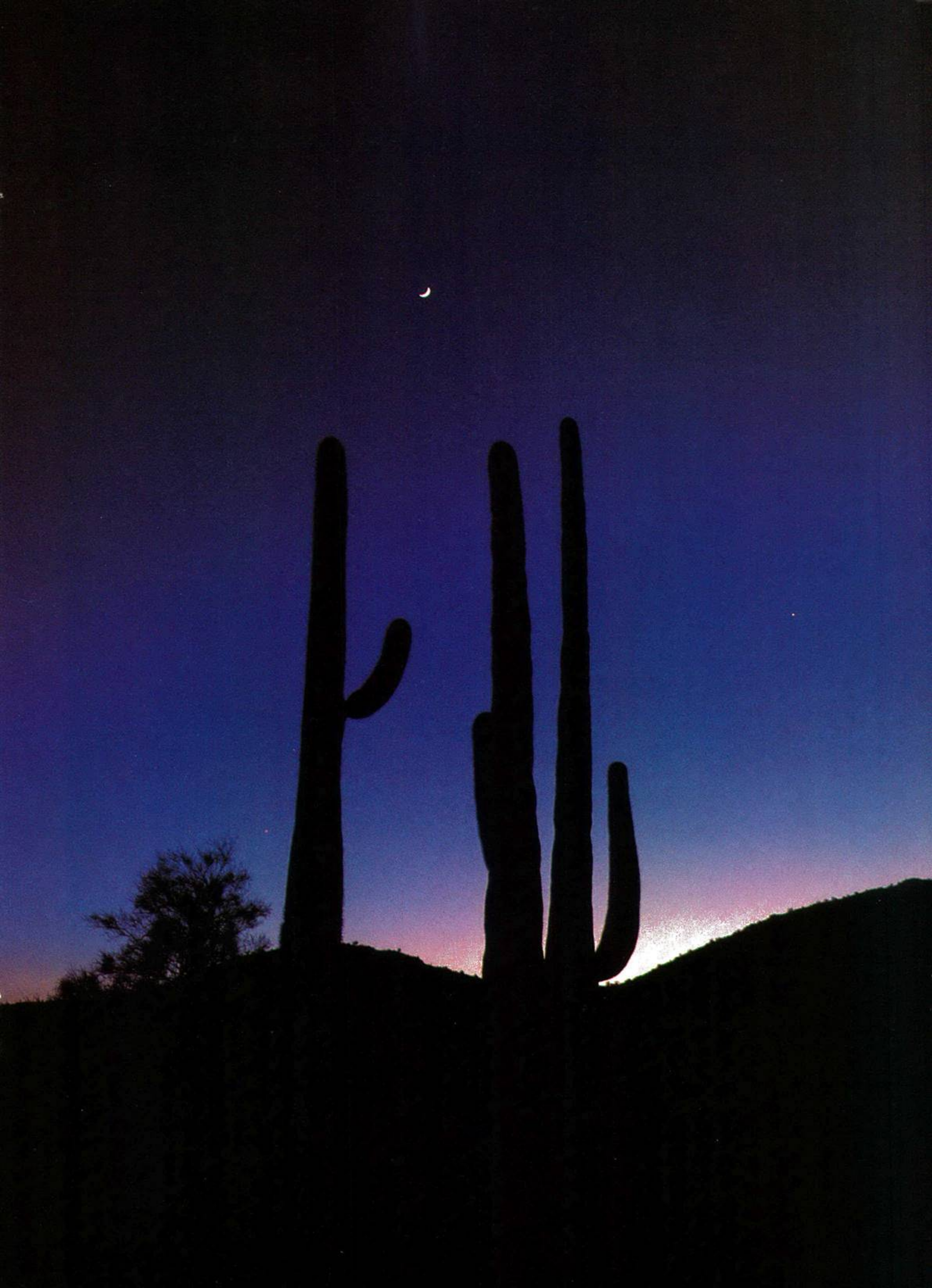
This month is a good time to look for **Uranus**. Brighter than magnitude 5.8, it should be visible with the naked eye from a dark site. Next month, it may be too close to Jupiter for easy sighting.

But planets are not the only solar-system bodies to look for in April. After moonset early on the mornings of April 21 and 22, the **Lyrid meteors** will be speeding from high in the sky — from almost overhead in most of the United States. One of these mornings will probably be close to the peak. This shower will be especially worth watching in 1983 because of its performance last year. The Lyrids were probably the most dependably numerous meteors of ancient times, but they have dwindled to a smattering of about 10 to 15 meteors per hour in recent years. There are exceptions, however, and 1982 was one of them. On the night of April 21-22 last year, many observers experienced one of the best Lyrid displays of modern times. Rates of about 60 to 80 Lyrids an hour were observed for a few hours. It is not at all likely that we will have a repeat performance this year — but who would want to take the chance of missing a rare revival of this once great old shower?

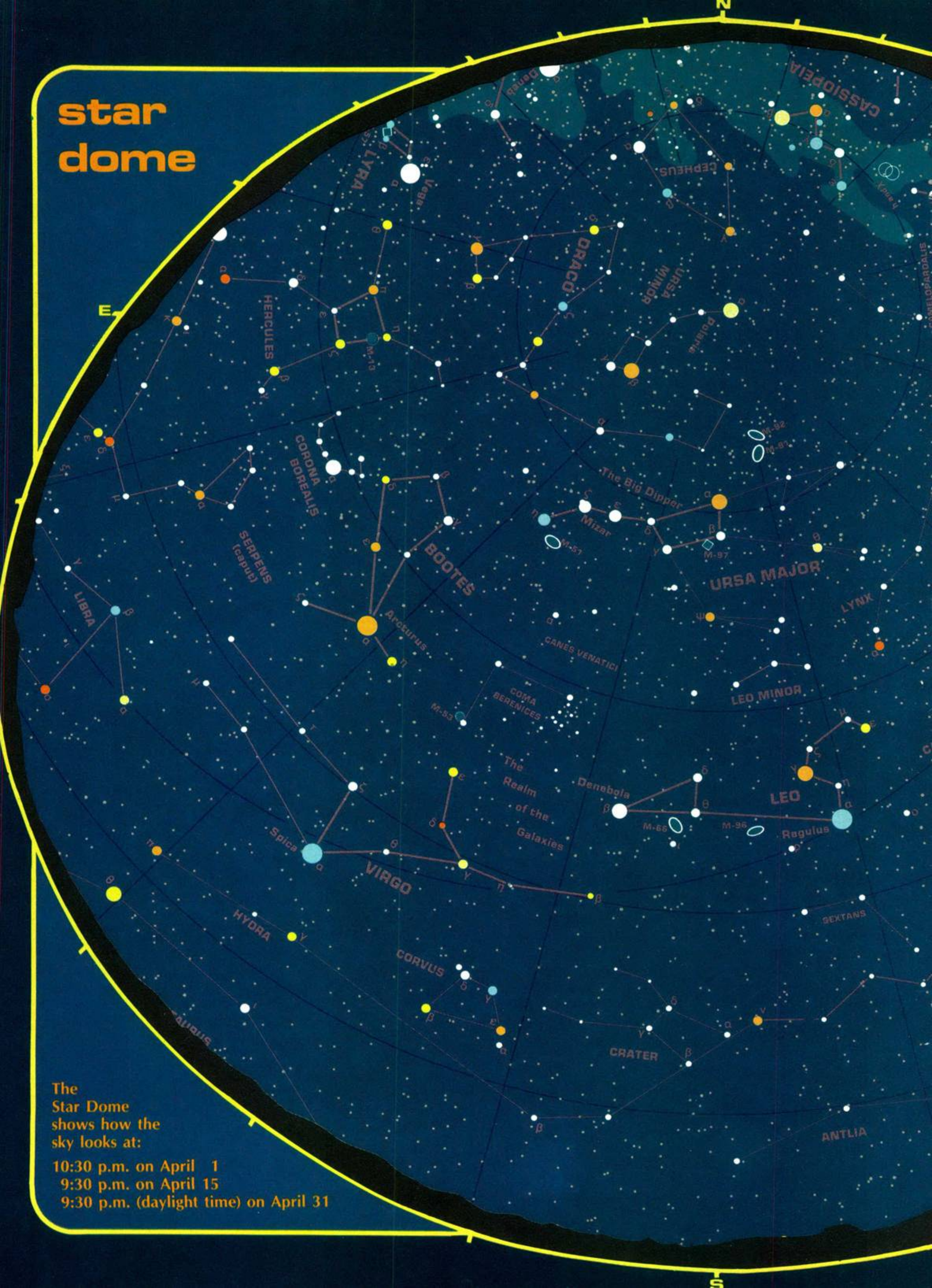
the starry sky

The traditional constellations of spring consist almost entirely of dangerous beasts and maidens. The beasts lead the way, with the two grandest animals among them represented by the two brightest constellations of spring. On April evenings these brilliant beasts are poking their heads over the meridian. But a lesser — and far fainter — creature of spring precedes them. Cancer the Crab is, despite

After loading his camera with 64 ASA film and setting it on a tripod, Kevin Ritschel made this photograph of the Moon and Venus over Organ Pipe National Monument in Arizona. This month a closer encounter will occur between the Moon and Jupiter.



star dome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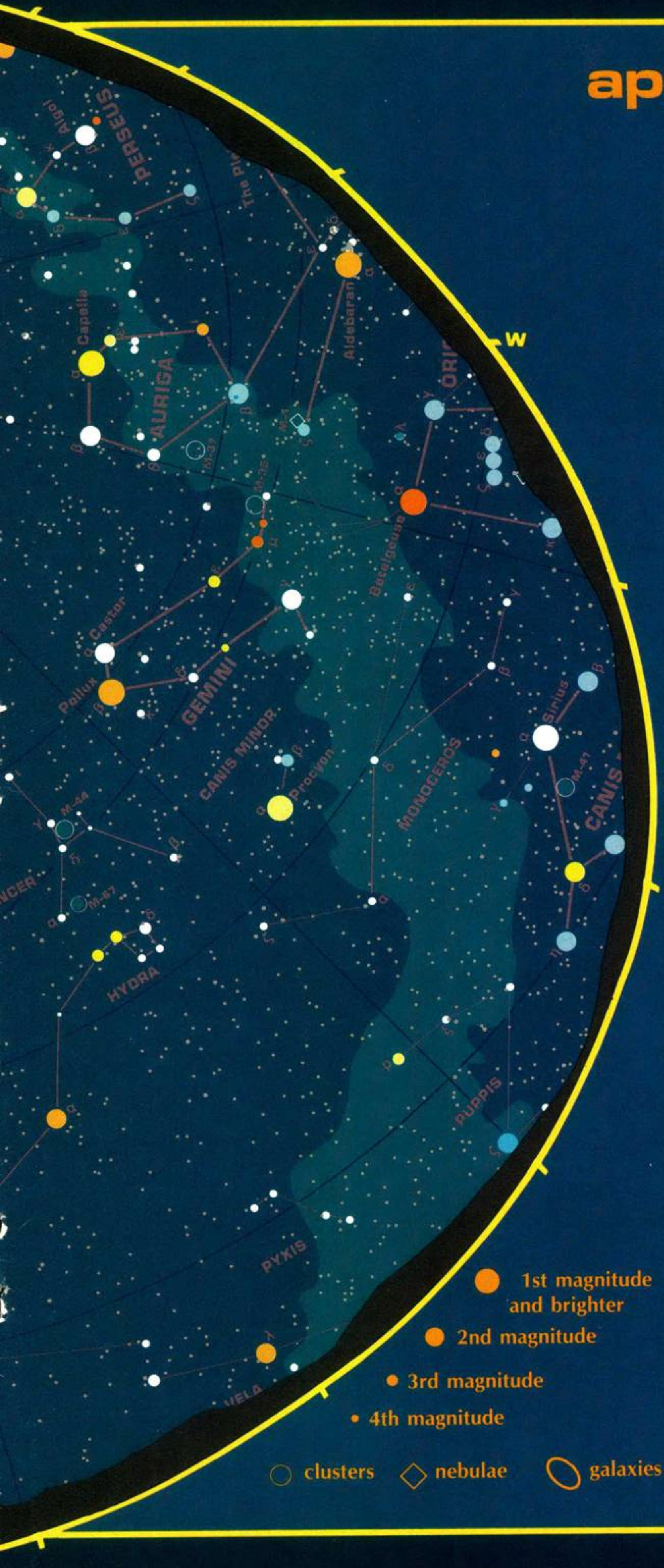
BOOTES
LYNX
LIBRA
Arcturus
CANES VENATICI
COMA BERENICES
M-53
LEO MINOR
The Realm of the Galaxies
Denebola
LEO
M-65
M-96
Regulus
Spica
VIRGO
SEXTANS
HYDRA
CORVUS
CRATER
ANTLIA

The Star Dome shows how the sky looks at:

10:30 p.m. on April 1
9:30 p.m. on April 15
9:30 p.m. (daylight time) on April 31


PERSEUS
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Procyon
MONOCEROS
Sirius
CANIS
M-41
M-44
M-67
CANCER
HYDRA
PUPPIS
PYXIS
VELA
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
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galaxies

april sky almanac

2nd An occultation of Jupiter will be visible from about half of North America, but will be best seen from the West Coast. The event takes place shortly before sunrise. (See text for details.)

5th Last Quarter Moon is at 3:38 a.m. EST.

6th The Moon is at apogee this afternoon: 251,307 miles.

7th Mercury passes through perihelion. You should see it very low in the west-northwest right after sunset. Between now and early May, when it vanishes from sight again, it will be visible in the early evening above the western horizon.

13th New Moon occurs at 2:58 a.m. EST.

14th Asteroid Vesta is in conjunction with the Sun.

18th Pluto reaches opposition.

20th First Quarter Moon is at 3:58 a.m. EST.

21st Venus passes through perihelion. The Moon is at perigee this morning: 229,751 miles. Mercury is at greatest eastern elongation, and is at its highest elevation in the western sky after sundown. Saturn is at opposition: it rises at sunset and remains in the sky the whole night through.

22nd The annual Lyrid meteor shower reaches peak activity during the day today. Be outside and looking toward the northeast during the early morning hours. If you are observing from a dark-sky location, you'll see about 10 to 20 meteors per hour. Don't pass them up — last year's display was far greater than expected.

27th The Moon is Full at 2:31 a.m. EDT.

30th If you look in the east around 1 a.m. daylight time, you can see the Summer Triangle — the bright stars Vega (in Lyra), Altair (in Aquila), and Deneb (in Cygnus) — rising above the trees and buildings.

In the autumn of 1978, John Woodland caught this spectacular auroral display intermingled with the stars of Ursa Major. He used a 50mm f/2 lens and 200 ASA film, which he exposed for 12 seconds.

its dimness, an extremely interesting constellation, and a good starting point for an April adventure in the sky.

Cancer is the almost empty area located about midway on the trip from **Pollux** and **Castor** — stars of bright Gemini in the northwest — to **Regulus**, the heart-star of the heavenly lion, now high in the sky. For naked-eye viewers or observers with binoculars, however, there is one fascinating attraction in the constellation, which is not a star.

Right in the midst of Cancer is one of the most famous of all star clusters — M-44, the **Beehive**. In fairly dark skies, naked-eye observers perceive this grouping as an odd and large (roughly 1½° wide) patch of uneven radiance. It might be possible in excellent conditions to pick out a few of the brightest stars of the cluster with the naked eye. At any reasonably good observing site, binoculars begin to show where this cluster gets its modern nickname: many paired and bunched stars of similar brightness glow together like a swarm of stellar bees.

M-44 was well known in ancient times, when its visibility was used as a weather predictor. Its Latin name was Praesepe — "manger" — with the stars **Gamma** (γ) and **Delta** (δ) **Cancri** near it being the Aselli, or "asses," coming to feed there. The ecliptic passes close to Asellus Australis (Delta Cancri), so that planets often pass near or even through the Beehive. There have been some beautiful passages by Mars and especially Jupiter in recent years, but in 1983 the journeys of Mercury and Mars through M-44 will occur when the Sun is too near for us to observe the cluster properly.

Directly below Cancer and the Beehive is the elegant little head of **Hydra**, the sea serpent or water snake. Hydra stretches across a greater east-west span than any other constellation; its length is more than six hours of right ascension. It underlines virtually the entire throng of the spring constellations — or is the outside crust of this seasonal slice of pie that has Polaris at its point.

It is fun to try tracing the length of Hydra star by star, but you need a good map and a fairly dark sky. If you don't have these, take a look at the head of Hydra and the serpent's lone bright star, which lies to the southeast of the head. The bright, ruddy star is second-magnitude **Alphard**, which marks the heart of Hydra. The name Alphard is Arabic for "the solitary one" — an appropriate title for the only prominent light in this dark corner of the heavens.

Things get brighter if we head east from Cancer or northwest from Alphard. High in the south — almost overhead in the southern U.S. — is **Leo** the Lion. His front half is the prominent asterism called the Sickle. If you have never seen a sickle, look for a backward question mark made up of six stars with a bright dot at the bottom. The dot is **Regulus**, which means "little king." The name was apparently given to the star by none other than Copernicus, though similar titles for the star were common at that period. Like the Beehive, Regulus is close to the ecliptic; hence it is a good "target" for the Moon and planets. The Moon will not occult the star in 1983, but we can look forward to three bright planets — Mercury, Venus, and Mars — passing within 1° of Regulus for observable conjunctions this year.

There are two other second-magnitude stars in Leo. One is **Algieba**, a famous double star located in the curve of the Sickle, or swell of the lion's mane. The other is **Denebola**, which is the rear extremity of Leo as he is now figured, and forms a right triangle with two other prominent stars of the Lion's hindquarters.

Although Leo has three stars brighter than magnitude 2.1, he is outdone in brightness by the Great Bear to the north, **Ursa Major**. This bear is a vast figure, much of which is actually rather faint, but the constellation is noted for the part of it that is the most famous of all asterisms — the Big Dipper.

Six of the seven stars of the Big Dipper are brighter than magnitude 2.4, and four are brighter than 2.0. Only **Delta (δ) Ursae Majoris** — Megrez — is fainter, at magnitude 3.3. **Dubhe** and **Merak**, the stars on the outside of the bowl, are the famous pointer stars that can be used to locate Polaris. On April evenings, when the Big Dipper is at its highest in the north, a line drawn through the pointer stars leads almost precisely to the North Star and the North Celestial Pole.

In addition to being clock, compass, and sign for finding many other constellations, the Big Dipper is also a good measuring-stick. The angular distance from Merak to Dubhe is 5°; from Dubhe to Polaris, 28°; and across the bowl's top (from Dubhe to Megrez), 10°. The size of the entire Big Dipper, lengthwise from Dubhe to the end star of the handle (Alkaid), is about 25°.

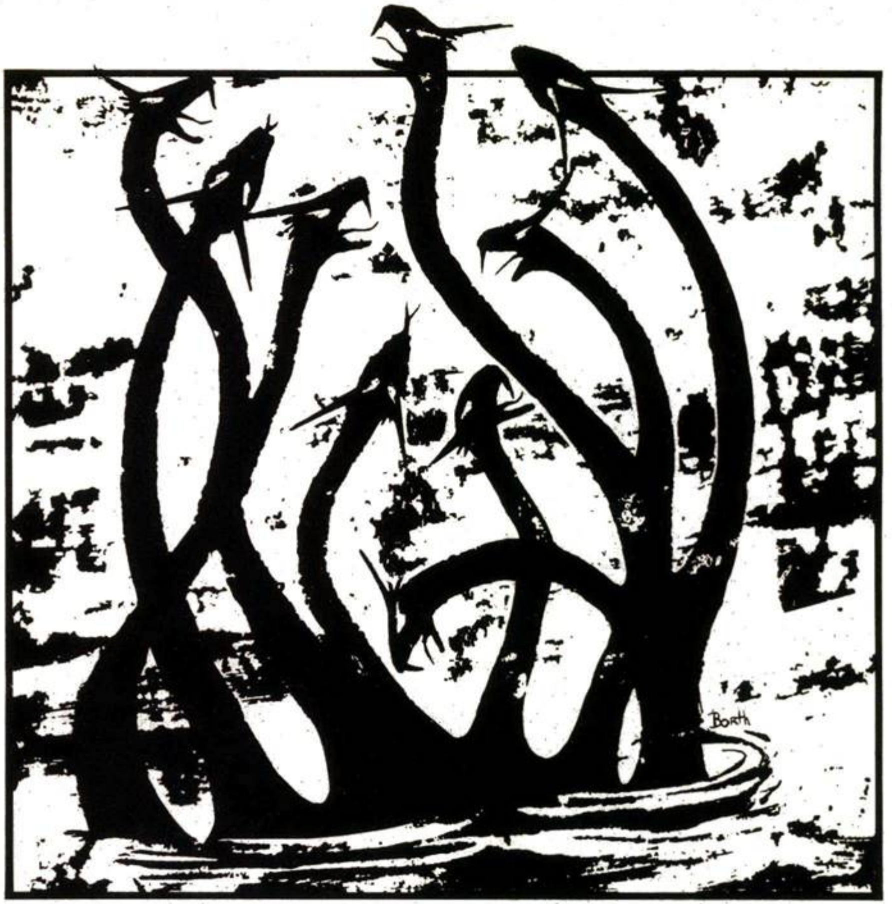
One of the best-known uses of the handle of the Big Dipper is its outward arc to **Arcturus** — at magnitude 0, the brightest star of spring. The old saying is that one can then drive a "spike" — a straight line — down to first-magnitude **Spica**. This month, however, you may also wish to extend the arc of the handle on past Arcturus to reach a bright visitor to the spring sky — Saturn.

There is much more to say about Ursa Major and many small but fascinating constellations and asterisms that can be found in this region of the heavens. We will make a tour of them next month.

skylore

One of the most famous monsters in Greek mythology was the Lernean Hydra. The ancient Greeks used the same stars to represent him as we now do, but their constellation was much shorter — the constellation was apparently not lengthened until after the 10th century A.D.

The Greeks and Romans closely associated Hydra with Corvus and Crater, considering them a three-part constellation — though they are listed separately in Ptolemy's *Almagest*. There are many tales relating the three, but the principal Greek legend about Hydra does not involve the crow and cup. It tells of the monstrous Hydra of the swamp at Lerna, and how his story — and coils — are entangled with the life and death of the great hero Hercules.



As the second of his 12 labors, Hercules was ordered to kill the Hydra. (The first of his labors was the slaying of the Nemean Lion, represented by Leo.) This assignment was one of the hero's greatest challenges. Lerna, located by the sea a few miles from the city of Argos, was close to several sacred sites — including the place where legend says that Hades seized Persephone and carried her down to the underworld. Visitors to the holy places were attacked by the Hydra, which lived by the sevenfold source of the river Amyone and roved in the Lernean swamp. The swamp was so deep that it could not be sounded when, in later centuries, the Emperor Nero ordered an attempt to be made. According to various accounts, the Hydra had 7, 8, 9, 50, 100, or even 10,000 serpent heads, all sprouting on long necks from a huge body, which some ancient authorities claim was dog-like. Whatever the original number of heads, however, one of the most terrible aspects of the Hydra was its ability to regenerate two heads in the place of any one that was cut off. The danger of the Hydra was not merely from its strangling coils: its breath and even its tracks, some said, were lethal. And one last attribute made it truly invincible: one of its heads was immortal.

Even Hercules was put to the test by this challenge. He had his nephew Iolaus shoot flaming arrows at the monster to lure it out. Then he tried lopping off the Hydra's heads while he held his breath against the monster's deadly exhalations — but this only multiplied the heads. As a dangerous annoyance, the hero's enemy Hera — who had raised the Hydra to combat Hercules — sent a giant crab scuttling out to nip at Hercules' toes as he struggled with the Hydra. This crab — thought to be represented by the constellation Cancer — was quickly eliminated with one crushing stamp of the strongman's foot.

Hercules was nevertheless in great difficulty and might actually have failed in this labor without the assistance of his nephew. Iolaus rushed up and set fire to the stump of each freshly severed neck, preventing the regrowth of new heads. Yet there was still one problem: what to do about the immortal head? Whether or not he cut it off, Hercules found the proper solution by rolling a huge rock onto it. Legend has it that the head is there today, as Jorge Luis Borges says, "dreaming and hating."

But although defeated, it was the Hydra that eventually proved to be the bane of Hercules' mortal existence. Hercules soaked his arrows in the Hydra's blood, which was a fearsome poison. Years later, the hero was tricked into putting on a shirt soaked in the blood of a victim of the poison and thus found himself cloaked in the wicked potion. The poison burned like a ceaseless fire, and though Hercules was strong enough to survive, he willingly gave up his life to escape the torment. But his story did not end tragically, for we are told that he was accepted by the gods and reconciled with Hera — thus, perhaps, explaining his Greek name, Heracles, "glory of Hera."

The Hydra was the offspring of Typhon, a whirlwind with a hundred dragon heads who temporarily overcame even Zeus, and of Echidna, who was half-woman and half-snake. Among their other children were other famous monsters, such as Cerberus, the Sphinx, and Chimera. The name or title "Hydra" is a feminine form of a word meaning "water creature." Some modern writers assert that Hydra is the female mate of Hydrus, a male water-creature constellation invented by Johann Bayer, a contemporary of Galileo.

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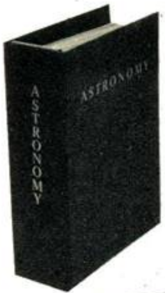

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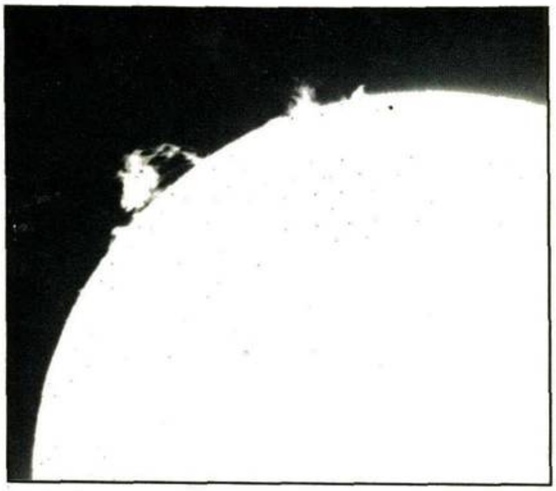

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how to star test your telescope

by
Dick Suiter

perfect, in-focus star image

Nothing beats top-notch optics in a telescope — right? But how do you *know* when your telescope has good optics? You've probably heard of optical testing, and perhaps the Foucault test, but what good is a test if you don't know how to do it? Well, there is one test that anybody can do, and *once you learn how to apply it carefully and correctly*, it can give you that reassuring glow that your 'scope is pretty good after all.

Everybody's probably heard of the Foucault test. It and variations on it are the standard amateur and professional optical shop method of evaluating telescope mirrors and lenses. To do it, you put the test piece at one end of a bench and shine light from a thin slit placed at the center of curvature on it. You then use a knife-edge to probe the confluence of light in the image of the slit formed by the lens or mirror.

However, for what you're probably interested in (i.e., the answer to the nagging question: "How good is my telescope?") the Foucault test isn't that good. Furthermore, a much more sensitive test exists, one that's good for all types of telescopes. Best of all, you needn't unmount the optics, and you can test with the entire optical system at once. This test is called the "star test."

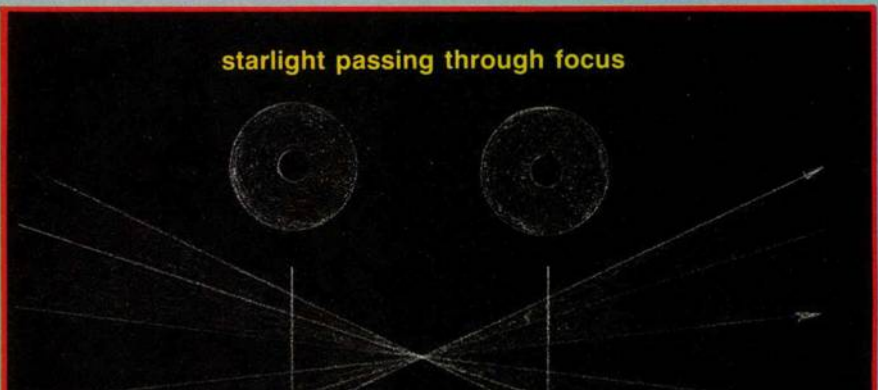
The star test involves considerably more than just focusing in on a star and saying, "Oh, that's nice," but a whole lot less fuss than making a Foucault test. What you do, in essence, is inspect unfocused star images both inside and outside the focal point. This allows you to deduce with considerable sensitivity what is going on at the focus. The star test was used to figure speculum metal mirrors long before the invention of the Foucault test, and it is used even today by the famous Mr. Dobson to figure the large mirrors of his telescopes.

You can use it, too. While the Foucault test is absolutely invaluable in the optical shop, the star test is an extremely useful "after-the-fact" test with the mirror in the telescope. However, before getting into star testing, let's first review a few of the major methods of testing telescope optics.

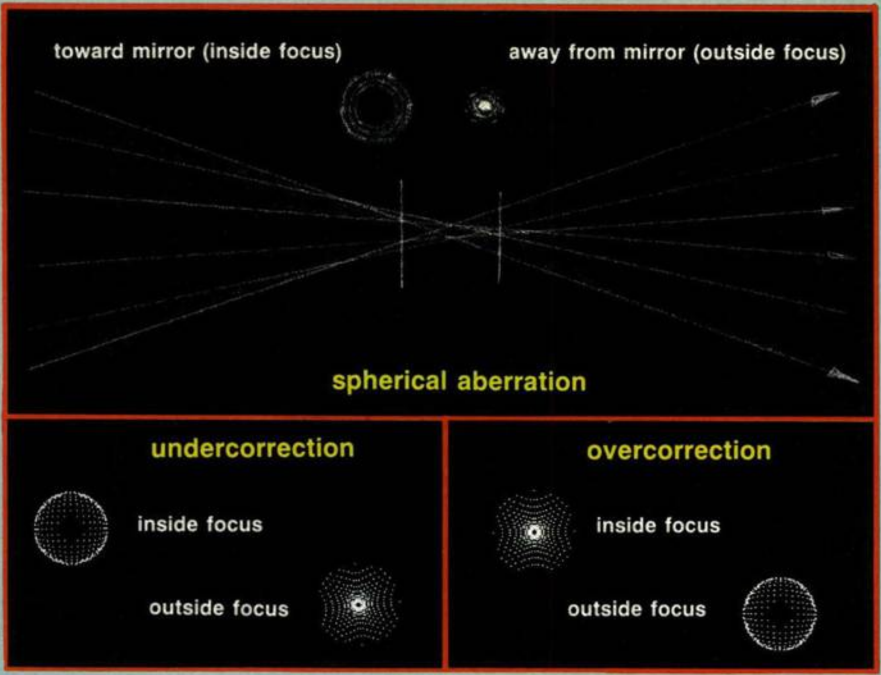
•*Actual Use*. Most people judge their instruments by using them in a normal manner, that is, they form an opinion of their telescope based on how their favorite objects, such as planets or double stars, appear in it as compared to other telescopes. This is okay as far as it goes, but has certain disadvantages. For one, even seasoned observers may apply the wrong criteria for judging performance. Second, very often that person has not looked through a really good instrument and doesn't really know how well a telescope *should* perform. Then too, other variables, such as alignment or air turbulence, can adversely affect the performance of an excellent telescope.

For example, a deep sky observer might informally rate a telescope by the appearance of diffuse nebulae at low power. At low power, however, the optical defects of the telescope itself are negligible — so what they're doing, in effect, is rating the performance of the eyepiece!

For the purpose of direct comparison, it is necessary to have looked through a really excellent telescope with the same aperture as the one you want to test. What is the likelihood of this? As it happens, really "excellent" telescopes are rare. Those of "very good" and "good" quality are much more common, and sad to say, about 20% of the telescopes I have seen deserve a "bad" rating. If your only standards of comparison are an old 60mm refractor and your neighbor's mediocre 6-inch reflector, you just aren't going to be able to make an accurate judgement



starlight passing through focus



based on general performance.

Finally, optical collimation is critically important. Unless the telescope is tuned up for top performance — that is, unless its mirrors and/or lenses are where they should be — you can't expect good performance. Unless you know how to look for and recognize misalignment, you could very well mislabel an "excellent" telescope as a "dog." Too bad for you. Too bad for the telescope.

•*Ronchi Screen Testing*. If you remove your telescope's eyepiece and put a ruled screen in its place, then look through that screen at a bright star, the projected pattern of lines on the mirror should be straight if the objective is "good." If there is any aberration present, the lines will be distorted — bent, non-parallel, or unequally spaced.

The trouble is that this test is too insensitive for critical evaluation. It'll tell you whether your mirror is good enough for low-power, deep-sky observing, but not whether it can handle critical planetary detail. Using the Ronchi test is roughly akin to taking a classroom ruler and holding it against a precision machined part, then solemnly proclaiming, "Yep, it's good to a thousandth of an inch." The Ronchi test will tell you if you have an incredibly bad mirror, but so will the star test.

•*Splitting Double Stars*. By all rights, testing with double stars goes under the "Actual Use" heading, but there are enough interesting features about double-star testing to justify discussing it by itself. And, of course, double-star tests have been the basis of many claims of optical superiority. However, there are some problems with using double stars as a test of optical quality.

Splitting doubles depends on sky quality. You may "test the sky" a dozen times before you check out your telescope rather than the atmosphere. Then, too, the shape of the diffraction pattern changes quantitatively rather than qualitatively with lowered optical quality. With lowered optical quality, the diffraction pattern *looks* pretty much the same, but there is less light in the central disk and more in the rings. A little extra light in the rings interferes relatively little with your ability to separate pairs of infinitely contrasty stars.

In spite of these disparaging comments, the double-star test has some validity because it measures something related to optical quality. If you are careful and understand what it proves (and what it doesn't prove), you can use it in conjunction with the star test to evaluate the image.

•*The Foucault Test*. Invented as a convenient way of checking optics in the shop, this test is still most appropriate in the shop. As a test, it tends toward being overly sensitive to defects in the center and not sensitive enough to disastrous errors at the edge. It's useful if you make a test, polish the mirror some more, then retest and see changes resulting from your work. As a "stand-alone" test of mirror quality, it requires an extensive series of micrometer knife-edge readings and a mathematical reduction.

Star testing and the Foucault test really can't be judged in the same terms. For an unaluminized, unfinished telescope mirror, the Foucault test is easy and convenient; but for a finished and assembled telescope, the star test makes a lot more sense.

•*The Star Test*. Well, finally we've reached the star test. How do you go about doing it?

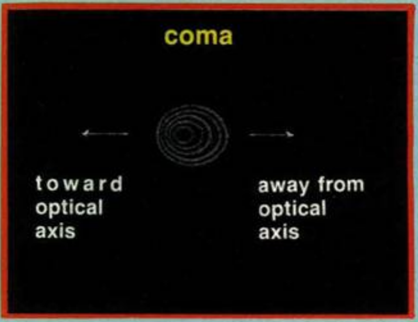
The first thing to do is set your telescope outside on a clear night and let it cool down. If it has an equatorial mount, point the polar axis in some direction other than north so you can use Polaris as a test star; equatorials are difficult to operate near the pole. Find Polaris and focus in on it using a high-power eyepiece.

What about seeing? You can do this test on a night when there is some atmospheric turbulence, because you are looking at a fairly large blur circle and not peering at the tiny in-focus image. You can identify the effects of turbulence — they are shaking and quivering — while effects due to optical errors in the glass are motionless.

A word about the eyepiece is in order. On most telescopes a focal length between 6mm and 8mm is sufficient, but the eyepiece must be one of dependable quality. If your telescope does poorly, try another eyepiece before passing a final verdict. If it fails again, try yet another eyepiece. At some point, though, you'll have to admit that (er, ahem) all of these eyepieces probably aren't bad, and it looks like (cough, cough) the telescope.

Okay, let's star test. Focus slowly from one side of focus to the other, then back again. Watch how things change. Notice that if you rack a little out of focus, either inward or outward, the star image expands into a disk. You can think of this as an in-focus view of the out-of-focus image. What you see represents a slice of the cone of light from the mirror coming toward a focus or expanding again after it's gone through focus. In Schmidt-Cassegrain telescopes (SCTs), Newtonians, and all other telescopes with secondaries, there is a dark shadow cone inside the cone of light where starlight was blocked by the diagonal.

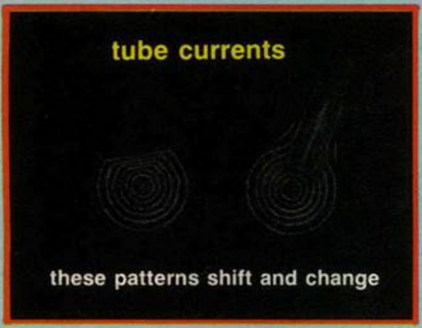
Focus back and forth again and again; try it slow, fast, oozingly slow, then "snap-snap" back and forth. Don't rush it — you are trying to store and compare a whole series of patterns from both sides of focus in your head. How far should you focus back and forth? There is no hard and fast rule — it's something you'll have to learn from experience. Generally it's a small amount, somewhere between 1/16 and 1/8 inch with a Newtonian, or a turn or so on the focus knob of an SCT. You should rack out far enough to see about six diffraction rings if you see rings at all, which you probably won't in fast reflectors.



Rings? What's going on? As the light

waves from different parts of the mirror come together to a focus, the waves "interfere" with one another, causing local crests and troughs of dark and light. These you see as rings in the out-of-focus star disk.

These rings are quite sensitive to departures from perfection. If the light is coming to a perfect focus, the appearance of the out-of-focus pattern outside and inside focus will be identical. If you have a perfect telescope, what you will observe both inside and outside focus is an evenly illuminated disk with a delicate ring pattern on it, and a slightly brighter outermost ring. The drawings show only roughly how it should look, though you should remember that no drawing can ever convey the delicacy of the actual patterns. Focus from inside to outside focus, comparing them.



Now that you have a general idea of how the star test is done, let's discuss what you might see with a less-than-perfect telescope.

•*The Case of the Misaligned Optics*. If your telescope is misaligned, you can do no further testing until it has been properly adjusted. The pattern for a maladjusted Newtonian reflector is a mixture of coma and astigmatism. This pattern changes as you move through focus, but the easy rule to remember is that the brightest side of the out-of-focus disk, the side with the crunched-up rings, is the side closest to the optical axis.

To collimate a Newtonian, adjust the three screws on the mirror cell (after consulting your owner's manual if you bought the telescope) to move the optical axis toward the center of the field. As you do this, keep recentering it and monitoring your progress. Admittedly, this a tiresome task much easier to do with two people — but you'll soon notice the pattern becoming centered and uniform as you approach axis. With SCTs, consult the owner's manual and *be careful* — collimate by the book!

Collimation is trickier with refractors; some have a "negative coma" pattern that is the reverse of the coma in reflectors, and some have so-called "coma-free" objectives that have no coma at all. These objectives will reveal their misalignment with the astigmatism pattern. If you can't remove the astigmatic pattern by adjusting the lens, you must conclude that the astigmatism is real — that is, it is a feature of the glass.

•*Tube Currents*. Tube currents plague big telescopes. Before you conclude that the optics of your telescope are bad, it's best to determine whether tube currents are troubling them. Well, what *are* tube currents? They're blobs of warm or cool air moving around inside the tube, acting like weak lenses and bending light rays so they don't reach a perfect focus. As the air moves around, the pattern of distortion changes. Rack quite a way out of focus and watch the show.

You can tell whether you have tube currents by having a friend frantically fan the end of the tube while you watch the star image. If the patterns disappear momentarily, act all stirred up, or at least change, you have tube currents. Defects on the glass are sickeningly permanent.

If you find tube currents, you haven't waited long enough to let the telescope equilibrate. Warm or cool air comes from a telescope tube, mirror, or any other part that's warmer or cooler than the ambient air. Wait a while, then test again. If your telescope always has tube currents, you may want to consider changing from that ¼" solid steel tube to one made of a lighter, less heat-holding material.

•*Pinched Optics*. If the cell holding the mirror is too tight, the mirror can be bent out of shape, and the pattern will appear distorted. A few sample distortions are illustrated. Naturally, these aren't the only patterns of this type. If your telescope fails the test, remount the optics somewhat less tightly, recollimate, and test again. Optics, ideally, should be mounted with a featherlight touch.

•*Spherical Aberration*. If you imagine light from a spherical mirror moving through focus, you can get some notion of the effect of spherical aberration, which is what you *remove* when you parabolize a mirror. In spherical aberration, rays from the center of the mirror focus farthest from it. If you're focusing inward, you see the central rays focus first, then rays from the outer parts of the mirror. This error is possibly the most common defect in fast (i.e., low f/ratio) commercial mirrors. If you recognize the pattern, that's what you've got.

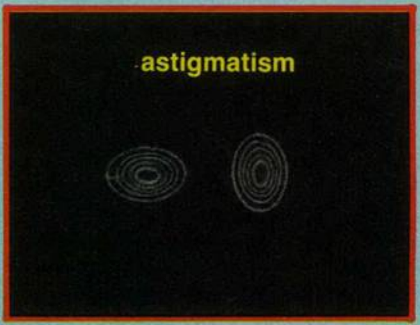
This particular pattern is called undercorrection. The opposite pattern is called overcorrection — that is, the mirror has been "parabolized too much." The sequence of patterns then appears reversed — what appears *inside* focus for the sphere or ellipse appears *outside* focus for the hyperbola.

The drawings show undercorrection in a fairly strong form. To recognize it in a mild form, examine the brightness of the disk at both sides of focus. If it looks bright on the perimeter and weak in the middle on one side of focus, and beefy in the middle and weak on the outside on the other side of focus, then your telescope has some spherical aberration.

By the way, please note that the outermost ring *should* be a bit brighter than the rest of the rings, but the same amount brighter on both sides of focus. A little spherical aberration is okay and probably unavoidable in fast reflectors.

Well, since we're talking about perfection, how can you recognize a tiny amount of under- or overcorrection? The following simple and very sensitive test is easy to make: bring a star into best focus and carefully note the position of the focus knob (you may want to attach a measuring scale to it). Now focus inward until you *just* see the dark shadow of the secondary mirror in the center of the out-of-focus disk. Note how far you turned the focus knob. Return to the original position, then focus outward until you just see the secondary mirror shadow again. If the distances are equal, spherical aberration is absent. If the distance inside focus is less than the distance outside focus, your telescope is undercorrected; if *vice versa*, then it's overcorrected.

•*Turned Edge*. Years ago, amateur telescope makers used to fear the terrible down-turned edge, or "TDE." It is a worthy adversary. Its effect is to make the images look like they suffer from a case of the "fuzzies." TDE is easy to detect in the star test. You rack inside focus and look at the edge of the pattern: instead of crisply coming to a stop at the edge, it kind of "fuzzes" off into the darkness. Outside focus, the periphery of the mirror appears brighter than the normally brighter edge would appear.



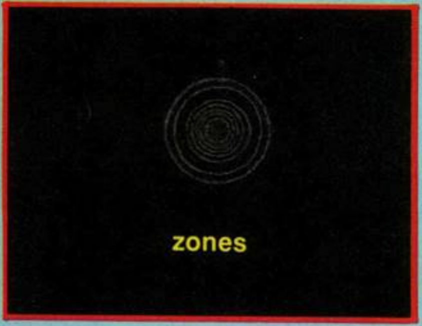
This is a good time to ask you to think when you star test, because some errors may look quite a bit like other ones. For example, you readily could mistake a TDE for overcorrection if you neglected to inspect the other side of focus. Also remember that you may see several errors occurring at the same time, so that on the whole it may be much easier for you to tell that something is not right, or that your telescope is imperfect (i.e., it flunks the "evenly illuminated pattern identical inside and outside focus" criterion), than it is to determine what is wrong with it.

•*Astigmatism*. Astigmatism has an unmistakable pattern — perpendicular oval out-of-focus disks on opposite sides of focus. It can creep in at any point in the optical system, including your eye; so if you see it, you must isolate it. Begin by rotating your head. If the pattern rotates too, make an appointment with an optometrist, because *you* have astigmatism. Next, turn the eyepiece in its mount. If the pattern turned with the eyepiece, discard the eyepiece. It has astigmatism.

If you have a Newtonian, and the pattern persists after eye and eyepiece check out, turn the mirror in its mount by 45°, recollimate the system, and test again. Now if the pattern turned with the mirror, cry, because that mirror needs replacing. However, if it didn't turn with the mirror, either the mounting for the mirror is bad or misadjusted or the diagonal mirror is pinched (i.e., mounted too tightly), or is defective.

•*Zones*. At some point in star testing, rack the eyepiece a bit farther from focus and inspect both sides of focus. If one part of the mirror has too much or too little correction, it will show up as a bright or dim zone in the supposedly uniform out-of-focus pattern. Usually zones that are obvious on one side of focus will be less obvious on the other.

•*Surface Roughness*. One of the more subtle effects to test for is a "lumpy" mirror surface — lumpy, that is, on a scale of millionths of an inch. Its effects include softening and smearing the out-of-focus diffraction ring pattern relative to what it should be. In fact, if you don't see extrafocal diffraction rings in the out-of-focus disk, it's probably because of surface roughness.



In focus, the effect is to make bright stars "look pretty," surrounded by a nice pattern of streaks and haze rather than the cold, hard points of light they should be. A mirror that's perfectly corrected for spherical aberration, astigmatism, zones and other problems may suffer from surface roughness.

Since this is a comparative test, you'll need access to a telescope with impeccable optical credentials, such as a first-rate f/15 refractor. Use a deep yellow filter over the eyepiece to eliminate chromatic aberration. After becoming thoroughly familiar with the contrast of its out-of-focus diffraction rings, check those of your own telescope. While reflectors and catadioptrics seldom meet the optical surface smoothness standard of a good refractor, if you can see rings, your telescope probably has acceptably smooth optics.

•*Chromatic Aberration*. Reflector owners need not worry about chromatic aberration, but refractor owners must check their instruments to see if they are properly achromatic. I don't have much experience in this area, so I will quote from H. Dennis Taylor, the inventor of the photovisual lens and the author of a book, *The Adjustment and Testing of Telescope Objectives*, now long out of print, on star testing.

"There is, perhaps, no better star for testing the colour correction of objectives of moderate and larger sizes than the pole star. If the telescope is directed to this star and the image examined with the magnifying power we have specified (50 to 70 times diameter in inches), then the appearance to be looked for, if the objective is nicely corrected, are a greenish yellow disc or ring system surrounded by a very narrow red fringe when the eyepiece is racked inside focus sufficiently far for two or three rings to be visible. The corresponding appearance when outside focus are the same greenish yellow disk, but without any trace of a red fringe, but, perhaps, a trace of a green fringe. Moreover, if the observer racks out of focus with great care, he will be able to notice a little bright red star disc, which forms itself just as the main focus is beginning to perceptibly expand. This is the focus for the less refrangible red rays beyond C.

"On racking outwards a little further, an indefinite blue focus will begin to form itself in the centre. On going further out still, until six or more rings can be counted, there will be a blue flare superimposed upon the greenish yellow ring system; it will about cover all the inner rings, scarcely reaching to the outer ring, while it grows brighter and more violet towards the centre of the system."

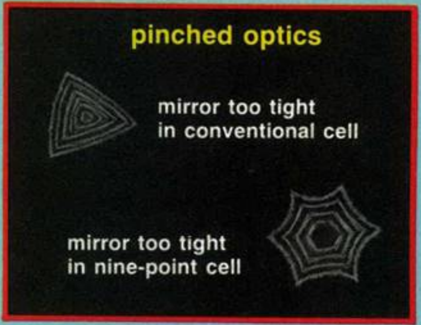
One final note on the star test: use it only on instruments where it's appropriate. A camera lens may star test miserably, but perform admirably for photography.

It's quite unlikely that you'll go out and perform your first star test flawlessly and understand perfectly what you see. One way to learn is to create some of the reversible errors in your own telescope — misalign it, or take it out and test it while it's still quite warm — but the best way is to test lots of different telescopes.

But before you go out into the world to star test every telescope you can, please listen to a serious word about star test etiquette. It should be obvious that you can star test a telescope, or think that you're star testing a telescope, in just a few minutes. That doesn't mean you have a right to tell people their telescopes are terrible. For one thing, you could be wrong.

You don't have the right to realign somebody's polar axis so that you can look at Polaris easily. The owner might have spent quite a bit of time getting it right. If other people are waiting in line to look through a telescope, come back some other time. If the owner didn't ask you to test his telescope, keep your mouth shut about what you see. If he asks what you're doing, tell him. He then may ask your opinion, but don't press it on him. If he asks, give him the results — but teach him how to star test.

Few telescopes can pass the star test with flying colors; it is far too demanding a test for that. This doesn't mean they are worthless — it merely indicates that they are not perfect, a fact that any amateur mirror maker or manufacturer would freely admit.


pinched optics
mirror too tight in conventional cell
mirror too tight in nine-point cell

So the real question is: "How imperfect can a telescope be before it's unacceptable?" That depends on what you bought the telescope for. Fast mirrors, those around f/4, are nearly always undercorrected. But if the patterns are approximately the same inside and outside focus, it's probably okay because you probably bought an RFT to use at low power on deep-sky objects.

We expect considerably more from general-purpose telescopes, those with an f/ratio of 6 or higher. As you rack from one side of focus to the other, you shouldn't notice any obvious difference between the patterns, although some is allowed. Certainly there should be no turned-down edge, and absolutely NO astigmatism.

If your interests lie in seeing faint, low-contrast planetary detail, then you must be a stickler for absolute perfection. It takes very little spherical aberration, coma, astigmatism, or surface roughness to wipe out the details you most want to see. Of course, you must realize that perfection, like everything else, costs money. If you have a bargain-price telescope, you have made a compromise.

Hopefully your telescope is a good one. You'll be able to breathe a sigh of relief upon testing it, confident in the knowledge that on a good night, your telescope won't really limit what you can do.

Dick Suiter is an amateur astronomer and telescope maker, a graduate student working toward his Ph.D. in nuclear physics at Ohio State University, and a frequent contributor to Deep Sky *magazine.*

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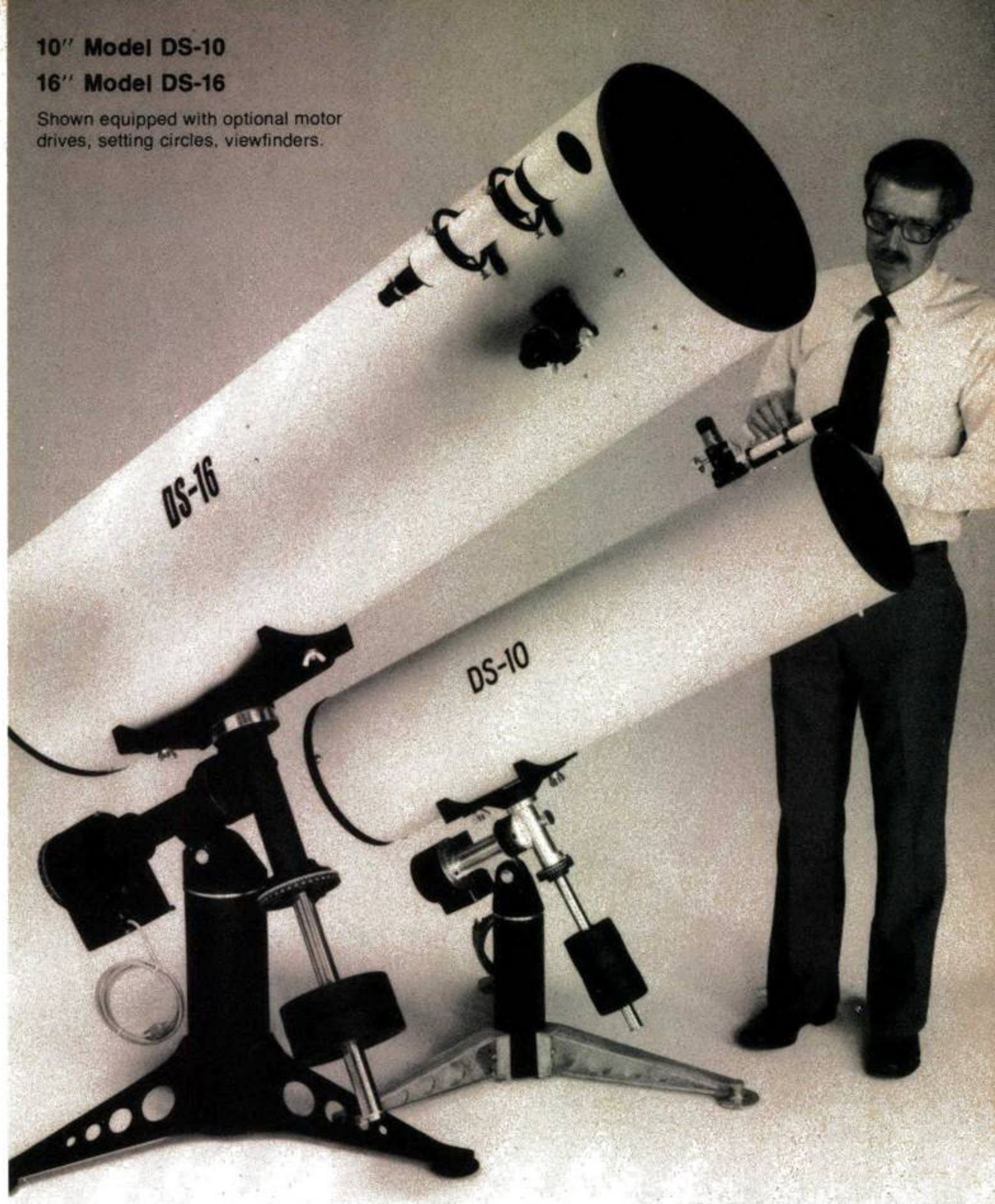
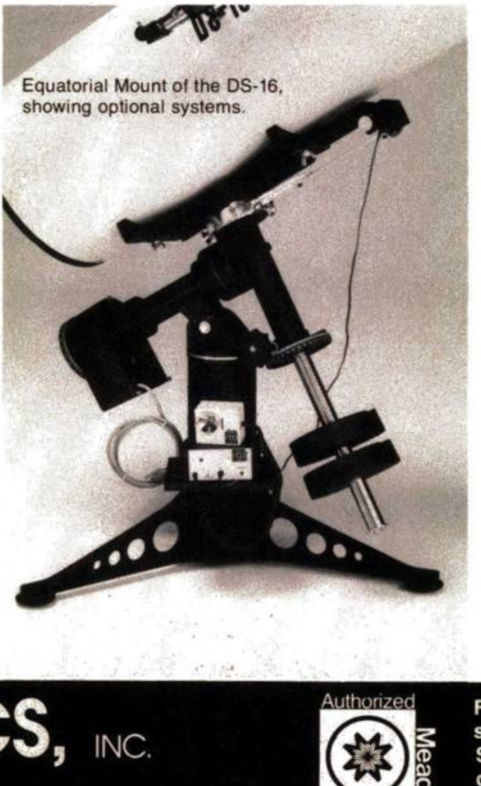


10″ Model DS-10

16″ Model DS-16

Shown equipped with optional motor drives, setting circles, viewfinders.



Equatorial Mount of the DS-16, showing optional systems.

OPTIONAL SYSTEMS

#787	**Electric Motor Drive System (115v./60Hz) for DS-10**	**$ 60.00 ppd.**
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See our ad on the next page for the wide array of other optional accessories for the DS-10 and DS-16. These include: higher- and lower-power eyepieces; viewfinders; telenegative amplifiers; nebular filters; drive correctors and photoguide telescopes for long-exposure photography; camera adapters. The giant Meade #680 Focuser may also be ordered in place of the standard focuser on the DS-10 and DS-16. See Bulletin DS for details.

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36— **ERECTING PRISMS**— Fully coated Porro prisms. Invert the astronomical image for terrestrial observations with astronomical telescopes. **1¼" O.D. . . . $29.75 ppd.; .965" O.D. . . . $25.75 ppd.**

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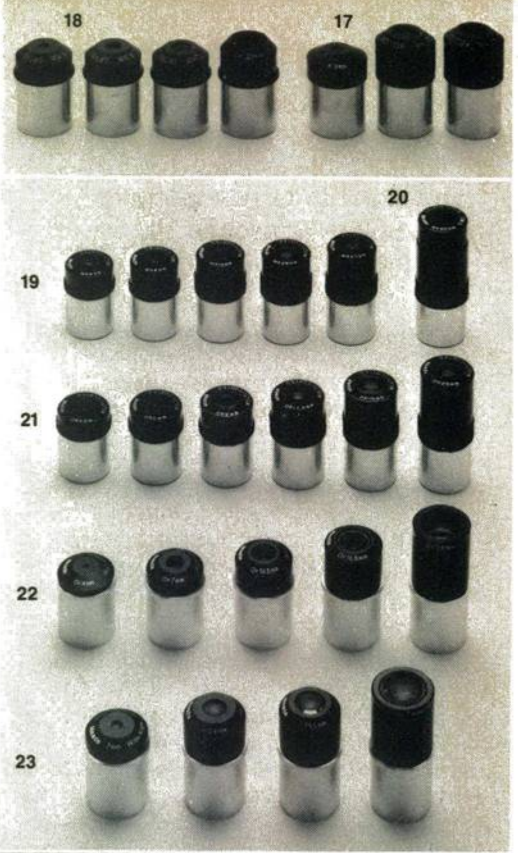

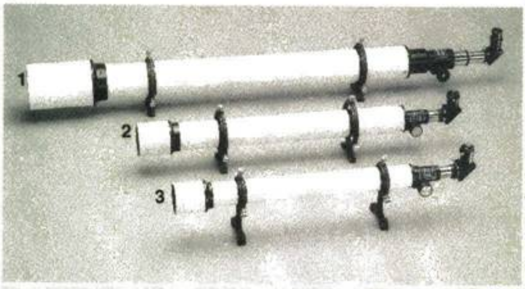

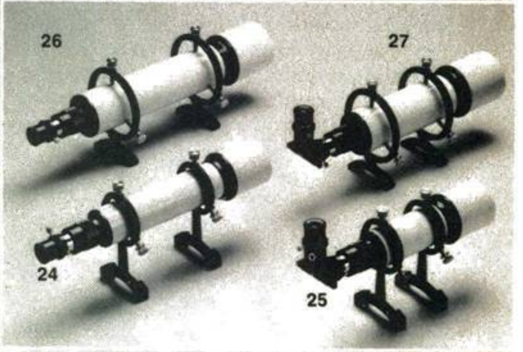

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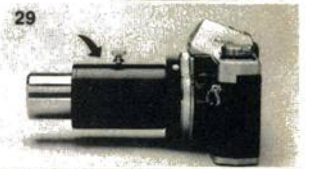
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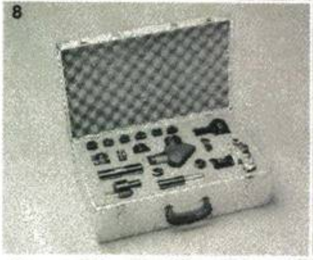
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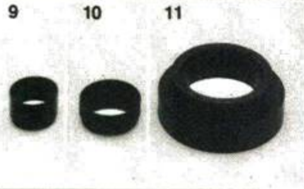

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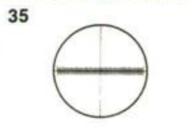
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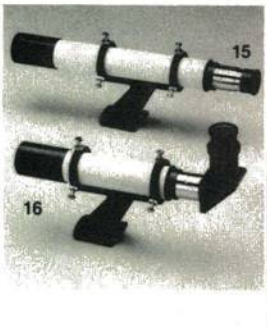

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Model 2120
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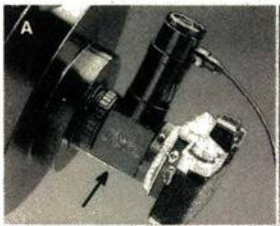

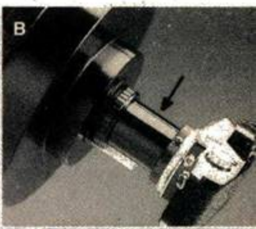

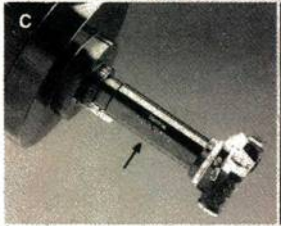

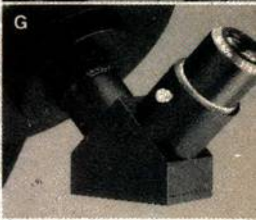

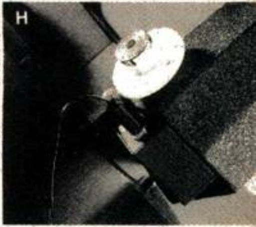

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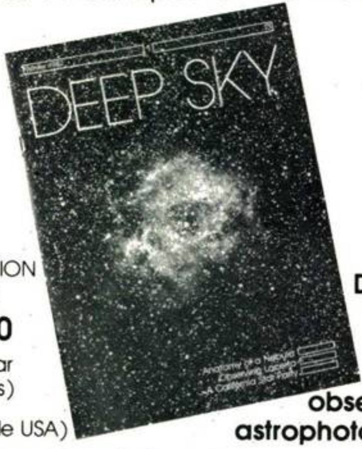

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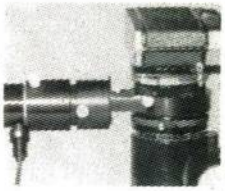

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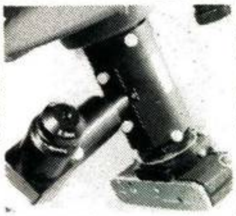

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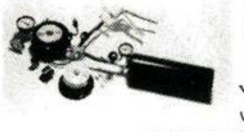

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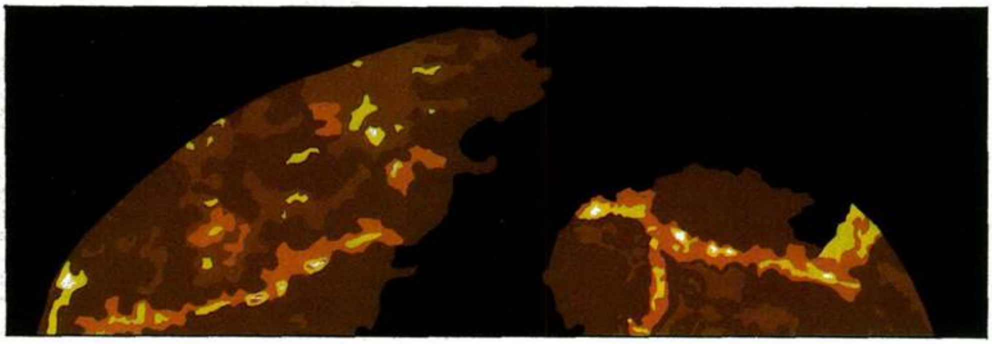

The Milky Way's obscuring dust hides the newly detected bridge between the Lynx-Ursa Major and the Pisces-Perseus superclusters. Color indicates numbers of galaxies in this map.

Largest Structure in the Universe

Astronomers have identified the largest assemblage of galaxies in the universe — 10 times larger than previously known superclusters. At an average distance of 200 million light-years from Earth, this string of galaxies is at least 700 million light-years long.

Riccardo Giovanelli of the National Astronomy and Ionosphere Center in Puerto Rico and Martha Haynes, assistant director of the National Radio Astronomy Observatory in West Virginia, detected a link between two superclusters of galaxies. The Pisces-Perseus and the Lynx-Ursa Major superclusters, named for the constellations they span, are separated by the Milky Way. Few galaxies are seen in the Milky Way itself because interstellar dust in the plane of our Galaxy obscures them — for this reason, the Milky Way is often referred to as the "zone of avoidance."

While the Galaxy's dust cuts off visible light, it does not obscure radio waves. Giovanelli and Haynes used the 1000-foot radio telescope in Arecibo, Puerto Rico, and the 300-foot dish in Green Bank, West Virginia, to find the suspected bridge between the two superclusters.

The constituent galaxies of this strung-out cluster are at approximately the same distance from Earth and are moving away from us at about the same speed. Whether the cluster galaxies had a common origin is not known, but Giovanelli and Haynes believe their research will aid scientists trying to determine how the universe evolved.

The discovery of the Pisces-Perseus Lynx-Ursa Major supercluster adds weight to cosmological theories claiming that the universe is homogeneous only when considered over very large scales and that galaxies and clusters of galaxies formed at a very early stage. The belief that the universe is homogeneous has had a powerful influence on modern cosmology.

Life in Europa's Oceans?

Researchers have identified a new place in the solar system — Jupiter's moon Europa — that might be capable of sustaining life if life-forms were transplanted there.

If the work of scientists Steven Squyres and Ray Reynolds of NASA's Ames Research Center in Mountain View, California, checks out, some low forms of Earth life could be transplanted and might well survive in the oceans suspected to exist on Europa. Squyres and Reynolds presented their findings at the American Geophysical Union meeting in San Francisco in December 1982.

Since no spacecraft has yet landed on Europa, the Squyres-Reynolds conclusion is based on Voyager photographs and other measurements. These appear, however, to make a strong case. Detailed analysis seems to show that Europa has a thick ice surface. The investigators believe the ice covers an ocean that could be 50 kilometers or more deep. This planet-wrapping ocean, in turn, seems to be covered by a skin of ice, perhaps five kilometers thick on the average. (Europa is a body just slightly smaller than Earth's Moon.)

The kind of terrestrial life that exists under conditions like those proposed for the europan ocean are those organisms found under the permanent ice of Earth's antarctic lakes. These organisms capture the small amount of sunlight they need for survival when it filters dimly through the thick permanent ice layer of the lakes. Adapted to these conditions, they could grow at light levels similar to those calculated to exist on Europa.

Life in Europa's oceans would require the heat of radioactive decay from the moon's rocky interior, heat from the tidal forces of Jupiter's gravity, and energy from sunlight. The first two sources are enough to keep most of Europa's ocean liquid; the third, sunlight, would provide energy for photosynthesis. Still other possible energy sources in Europa's oceans might be electric currents induced by Jupiter's enormous magnetic field or heat from volcanic vents in the ocean floor.

Photos taken during the Voyager flybys show Europa as perfectly smooth: it looks like a huge white billiard ball, netted with a giant pattern of dark lines. The pictures show that these lines range from one kilometer to 70 kilometers in width. Scientists believe the dark lines mark huge fracture zones.

Within these large fracture zones, Reynolds suggests, there are many relatively small cracks, too small to have been observed by Voyager's cameras. As the cracks form and freeze over, they may provide semi-transparent "windows" for sunlight to shine through into the ocean waters below. Squyres and Reynolds estimate the yearly average area of these thin-ice windows could amount to as much as 25 to 50 square kilometers. Any given ice window could support terrestrial organisms for about 5 to 10 years before its ice thickened too much to let light through. The total area of thin ice would provide up to 30 million watts of energy per year for any photosynthesizing organisms.

The evidence for an underlying ocean on Europa comes from scientists' observations that there is a continuous build-up of new frost on the moon's surface. In addition, calculations indicate that the heat of radioactive decay plus tidal flexing of the moon by Jupiter's gravity should be sufficient to keep most of Europa's water liquid. Without this internal heat, the moon would be mantled in a solid sheet of ice. But even though Europa appears to be covered in a deep ocean warmed from the inside, its surface is a shell of ice because it is exposed to the vacuum of space a billion miles from the Sun.

This skin of ice must be relatively thin, say Reynolds and Squyres, because we can see that the moon has an extremely smooth surface. For any planetary body to retain topographic features, the material of its surface must be strong or thick enough to support such features. Since Europa displays essentially no relief, its surface must be so thin that virtually all craters have been smoothed out.

The moon's internal heat is kept in by an "insulation blanket"; both Earth satellite and Voyager observations suggest that Europa has a fluffy surface texture. Reynolds and Squyres believe this is an insulating layer of frost. A frost layer would hold enough heat for an average near-surface temperature of 140° Kelvin. "This isn't hot," says Reynolds, but it is enough to soften the surface and smooth out craters and other scars found on virtually all solar-system bodies, and to deform a several-kilometer-thick ice shell into the smooth sphere observed.

Further evidence for an insulating layer and relatively thin ice shell comes from the fact that the planet's trailing hemisphere is only lightly coated with sulfur dioxide, believed to come from the volcanoes of its neighboring moon, Io. If Europa were not constantly generating new frost to cover it, the sulfur would build up and coat the entire moon thickly in just a few years — and this has not happened.

Every time Europa's ice shell is cracked open to expose liquid water, the frost layer builds up a little more: water bubbles up into the vacuum of space, freezes, and spreads out on the moon's surface as frost. The cracks appear to come from the tides Jupiter generates in the body of Europa. The gravity of two other moons, Io and Ganymede, constantly forces Europa's orbit into an elliptical form, varying its distance from Jupiter. This variation in distance means that the force of Jupiter's gravity on Europa also varies. As it circles Jupiter every 3½ days, the moon is alternately stretched slightly and then relaxed. As a result, it warms a bit, and the ice shell fractures.

Though their predictions cannot be tested further until the Galileo orbiter craft arrives at Jupiter later this decade, Squyres and Reynolds suggest that Europa could have a small number of "oases" in its oceans which might support life.

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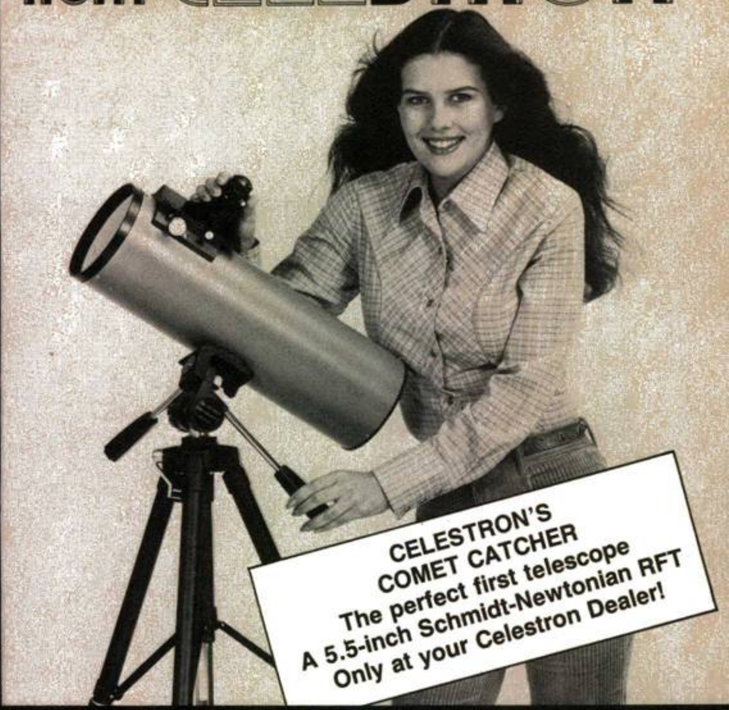

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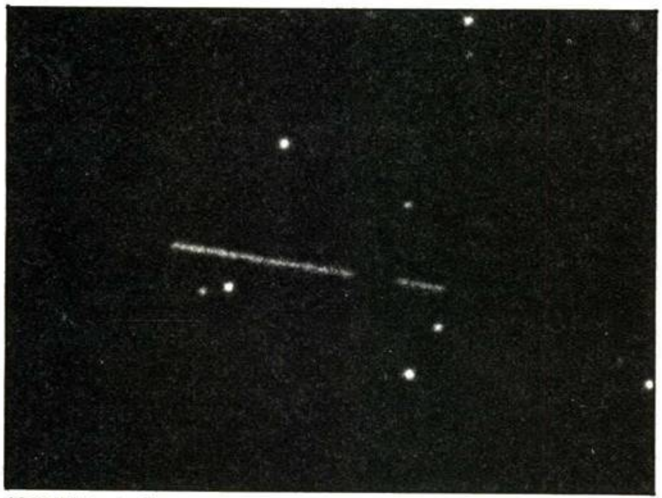

1982 TA's trail

Photo by E. Helin, Caltech

New Asteroid Found

A large new asteroid has been discovered by Caltech planetary astronomer Eleanor Helin using the 48-inch Schmidt telescope at Mt. Palomar. Temporarily designated 1982 TA, the asteroid may be the burnt-out remnant of a comet.

"While this asteroid does not seem to be a promising candidate for a space mission because of its orbital inclination and eccentricity, it is an exciting discovery," says Helin. "Its orbit compares closely with that of Encke's Comet and another unusual asteroid, Hephaistos. It is also one of the largest asteroids ever found outside the main asteroid belt." Moreover, Helin notes, it was found on its inbound journey toward the Sun and so will present an unusually long period for study.

1982 TA is a member of the class of asteroids known as Earth-crossers, or Apollo objects, and its spectral characteristics indicate that it is relatively large and dark.

Where Are the Oceanic Craters?

A chunk of rock and ice 5 to 10 kilometers in diameter plunges through Earth's atmosphere and into the ocean. Passing virtually unimpeded through kilometers of ocean, the asteroid hits the floor of the sea with most of its destructive power intact. According to Garry Rogers of the Canadian Pacific Geoscience Center, writing in *Nature*, the resulting crater should be about 100 kilometers in diameter.

Some 15 major impact sites (called astroblemes) less than 100 million years old have been identified on land — two of them greater than 50 kilometers in diameter. Yet to date not a single impact crater has been positively identified upon the two-thirds of the world covered by water. Why?

Perhaps one reason is that the ocean floor is systematically destroyed — subducted under continental margins — and renewed at spreading mid-oceanic ridges. Even so, large areas of ocean floor are older than 100 million years and should have sustained as many impacts as a similar area of land. Astroblemes on land are characterized by large circular structures, meteorite fragments, and evidence for changes in the surrounding rocks caused by impact shock — all characteristics which are difficult, though not impossible, to identify under kilometers of water. Despite this, our knowledge of submarine topography and geology is sufficient to see such structures if they are there.

Rogers suggests we may be looking for the wrong thing. An ocean impact, he says, might be very different from a continental one. The result need not be a conventional crater.

What might be expected? The material at the center of a crater formed by a large impact rebounds upward, creating an uplift which can be as large as one-tenth the crater diameter. In an ocean impact of this magnitude, such an uplift could reach or rise above sea level. Meanwhile, the main body of the asteroid would penetrate the sea floor and continue down into the mantle. It would generate widespread and possibly long-term volcanism, which could reach far beyond the impact area because the thin ocean crust would be extensively fractured.

The central uplift could thus increase while the rest of the crater is obliterated. Over the subsequent 1 to 10 million years the uplift would slowly subside until it reached equilibrium with the surrounding crust — both floating upon the fluid mantle beneath. However, water mixing with melted and upthrust mantle material would result in a net volume increase. Even after equilibrium had been reached, such a structure would stand above the ocean floor.

With this altered model for an impact in mind, is there anything we know of in Earth's oceans that might fit these characteristics? Rogers suggests the deep ocean plateaus. These rarely encountered structures range up to several hundred kilometers in diameter and appear to consist of tall yet flat areas of thickened ocean crust. Although often lying at depths too great for such formations, some plateaus are covered with calcareous sediments, which accumulate only in comparatively shallow water, and shallow-water fossils. They also contain basalts in which the size of the holes caused by the escaping gas shows that the rocks cooled under low pressure and therefore at a shallow depth. All of this evidence indicates that these plateaus once stood higher than they do today.

Another line of evidence: Earth's magnetic field reverses its polarity with a fairly regular period. As the sea floor is steadily created at mid-oceanic ridges, these field reversals manifest themselves as stripes of alternating magnetic polarity in the newly formed crust. The magnetic signature of the plateaus suggests they were formed relatively rapidly.

Finally, Rogers points to the increasing body of evidence supporting the idea that mass extinctions 65 million years ago — including that of the dinosaurs — may have been caused by the impact of an asteroid. Preliminary dates on the youngest plateaus indicate that they are older than 100 million years, which exonerates them in this case. Since the fossil record shows that the formation of these plateaus did not result in extinctions, an impact-generated plateau connected with the extinction of the dinosaurs would have to be much larger than any currently visible.

Perhaps the ocean floor on which it rested has already passed under a continental margin. But a plateau of the required size would not be subducted easily, and some evidence for such an event would probably survive. Since the greatest extinction of higher plants occurred around the margin of the present-day North Pacific, Rogers suggests that this may be the area in which to look. "A tectonic event of the appropriate magnitude might be the abrupt change in the motion of the Pacific plate about 45 million years ago."

To prove whether or not the deep ocean plateaus do in fact have anything to do with asteroidal impacts, researchers will have to search for crater remains and shock damage to nearby rocks. They should also investigate known continental impacts for large-scale geochemical effects characteristic of impacts on the ocean floor. *Donald F. Robertson*.

Frozen Methane Found on Pluto and Triton

For the first time, researchers have found frozen methane on two outer bodies in the solar system — the planet Pluto and Neptune's largest satellite, Triton. These findings indicate that Pluto and Triton have surfaces that are very different from any other bodies orbiting the Sun.

A molecule of methane is composed of one atom of carbon and four of hydrogen. Methane is a gas at temperatures above 50° Kelvin. When the temperature falls below this, methane freezes solid.

According to Jerome Apt of the Jet Propulsion Laboratory, methane is usually frozen on the surface of Pluto. This planet journeys far from the Sun during most of its 248-year orbit, but between 1979 and 1999 it will be traveling inside the orbit of Neptune. At aphelion, the temperature on Pluto's surface drops below 50° K, but when Pluto approaches the Sun more closely (as it is now doing), the temperature should rise to about 65° K — and some of the frozen methane ought to evaporate and form a thin atmosphere. Apt says that his team members who observed Pluto have indeed seen evidence of gaseous methane.

Triton's methane appears to be solid ice; however, Apt says that no sign of the gaseous form has been found there. By observing Triton as it moves around Neptune and presents different faces toward Earth, some team members — astronomers from the University of Hawaii and JPL, led by Dale P. Cruikshank of the University of Hawaii — have deduced that methane ice does not cover the surface uniformly, but exists in great continent-sized patches.

"Most of the other satellites in the outer solar system," Apt says, "are

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ASTRO NEWS

markedly different from Triton and Pluto. The other satellites of the outer solar system have surfaces that are primarily water ice." (The exception is Saturn's largest satellite, Titan, which has a dense atmosphere of nitrogen and methane gas.) "Water and methane are, of course, very different materials. It is likely that with our observations of Pluto and Triton we will be able to learn more about the primordial cloud of dust and gas that formed the solar system," Apt says.

Scientists have found that the composition of planets and satellites changes with distance from the Sun. They say this was caused by a cosmic "stirring" that went on in the cloud of dust and gas during the formation of the solar system. By understanding those processes, scientists hope to be able to understand better the large-scale geology and mineral distribution on Earth and the other planets.

Apt and his fellow astronomers are encouraging scientists in the Voyager project to make careful, extended observations of Triton when Voyager 2 makes its closest approach to Neptune in 1989. "Voyager 2's cameras could take detailed images of Triton's surface to provide information on what amounts to an exotic physics laboratory at the edge of the solar system," Apt said.

Neither Voyager 2 nor its twin craft, Voyager 1, will approach anywhere near Pluto, so we will be unable to make any observations of that planet. It is possible, however, that an infrared instrument aboard the orbiting Space Telescope may be able to observe Pluto by the mid-1980s.

Meanwhile, observations will continue at NASA's Infrared Telescope Facility on Mauna Kea in Hawaii and at JPL's Table Mountain Observatory in California to further study Triton's surface features, and to monitor Pluto's changing atmosphere as the planet makes its closest approach to the Sun in 1989.

ASTRO CALENDAR

April 1-3	**2nd Annual Conference on Space Development,** "Doing Business in Space." Houston, Texas. Contact: L-5 Society Conference, 114 Byrne St., Houston, TX 77009.
April 9	**7th Astronomy Invitational.** East Lansing, Michigan. Four-member teams meet in question-answer competition. Contact Jenny Pon, President, MSU Astronomy Club, Talbot Abrams Planetarium, East Lansing, MI 48824.
April 23	**Astronomy Day.** Astronomers everywhere are urged to set up telescopes and show friends, neighbors, and the general public a view of the heavens. Members of the Astronomical League will celebrate Astronomy Day on May 14.
May 9-12	**6th Princeton Conference on Space Manufacturing,** co-sponsored by Space Studies Institute, Princeton University, Princeton, New Jersey. Contact: April Whitt, The Space Studies Institute, Box 82, Princeton, NJ 08540.
May 27-30	**Riverside Telescope Maker's Conference.** Big Bear, California. Contact: Clifford Holmes, 8642 Wells Ave., Riverside, CA 92503.
June 3-6	**Convention of the Mid-States Region of the Astronomical League.** William Jewell College, Liberty (Kansas City), Missouri. Contact: Tom Martinez, Chairman, 1208 Somerset Ct., Blue Springs, MD 64015.
June 8-12	**Texas Star Party,** Fort Davis, Texas. Annual meeting of the National Deep Sky Observers Society will be held in conjunction with the Star Party. Contact: T.S.P. '83, Dept. A, 2709 Colonial Dr., Carrollton, TX 75007. Phone (214) 242-4908.
June 13-19	**Joint Meeting of the Astronomical Society of the Pacific and the Western Amateur Astronomers,** on the Kona coast of the Big Island of Hawaii. Contact: Hawaii Meeting, A.S.P., 1209 23th Avenue, San Francisco, CA 94122.
June 20	**25th Annual Summer Science Program.** Ojai, California. Contact: Administrative Director, Summer Science Program, Thacher School, Ojai, CA 93023.
July 14-16	**4th Annual Fairborn Symposium,** "Microcomputers in Astronomy." Fairborn, Ohio. Sponsored by IAPPP and AAS/SIGUMA. Groundbreaking for Fairborn Observatory one-meter telescope, July 15. Contact: Microcomputers in Astronomy, c/o Fairborn Observatory, 1247 Folk Rd., Fairborn, OH 45324.
July 26-30	**ALCON '83** — national convention of the Astronomical League. Jacksonville, Florida. Contact: Michael Reynolds, P.O. Box 1170, Jacksonville Beach, FL 32250.
August 5-6	**Stellafane.** Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776.
August 1984	**6th World General Assembly of International Union of Amateur Astronomers.** Bologna, Italy. Contact: Dr. Luigi Baldinelli, c/o A.A.B., Casella Postale 1630 AD, 1-40100 Bologna BO, Italy.
October 27-29	**Great Plains Planetarium Association Conference.** Hastings, Nebraska. Contact: Mitch Luman, J.M. McDonald Planetarium, 1330 N. Burlington, Hastings, NE 68910.

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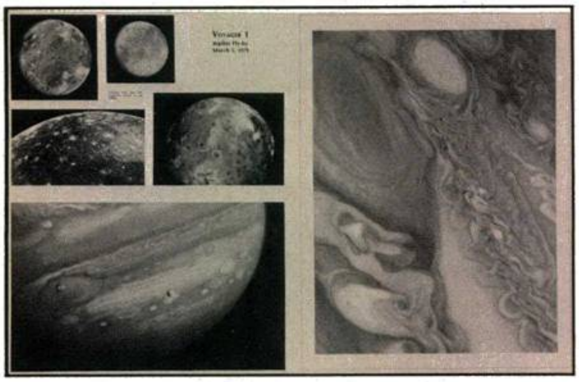
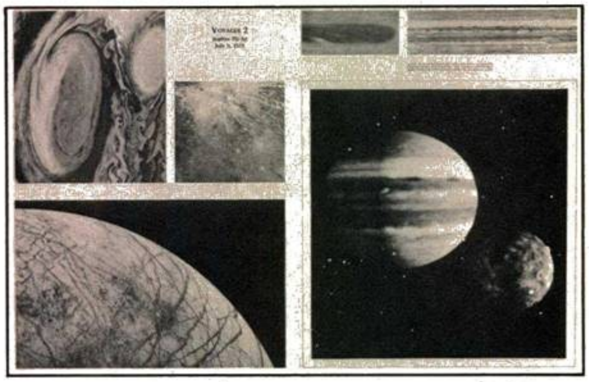
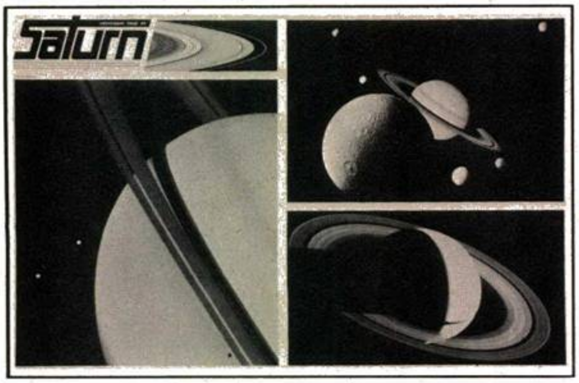
JUPITER 1. Images from Voyager 1 of the Red Spot, floating satellites against the planet and close-ups of the fabulous Galilean moons.

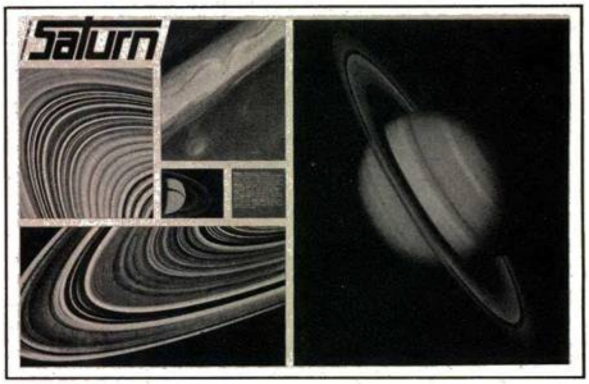


JUPITER 2. Six more unduplicated photos of the miniature solar system from Voyager 2. A perfect complement to the Voyager poster at left.





SATURN 1. The jewel of the solar system reveals its hundreds of rings, radial spokes and curious collection of satellites.



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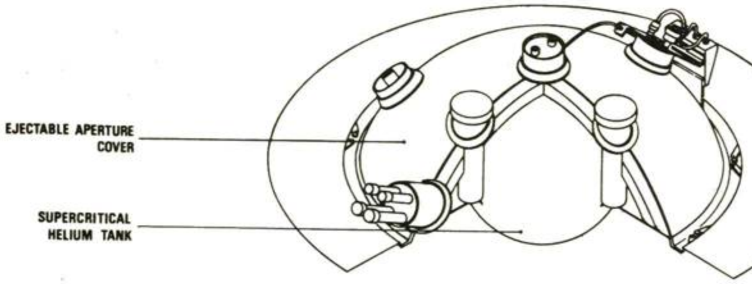
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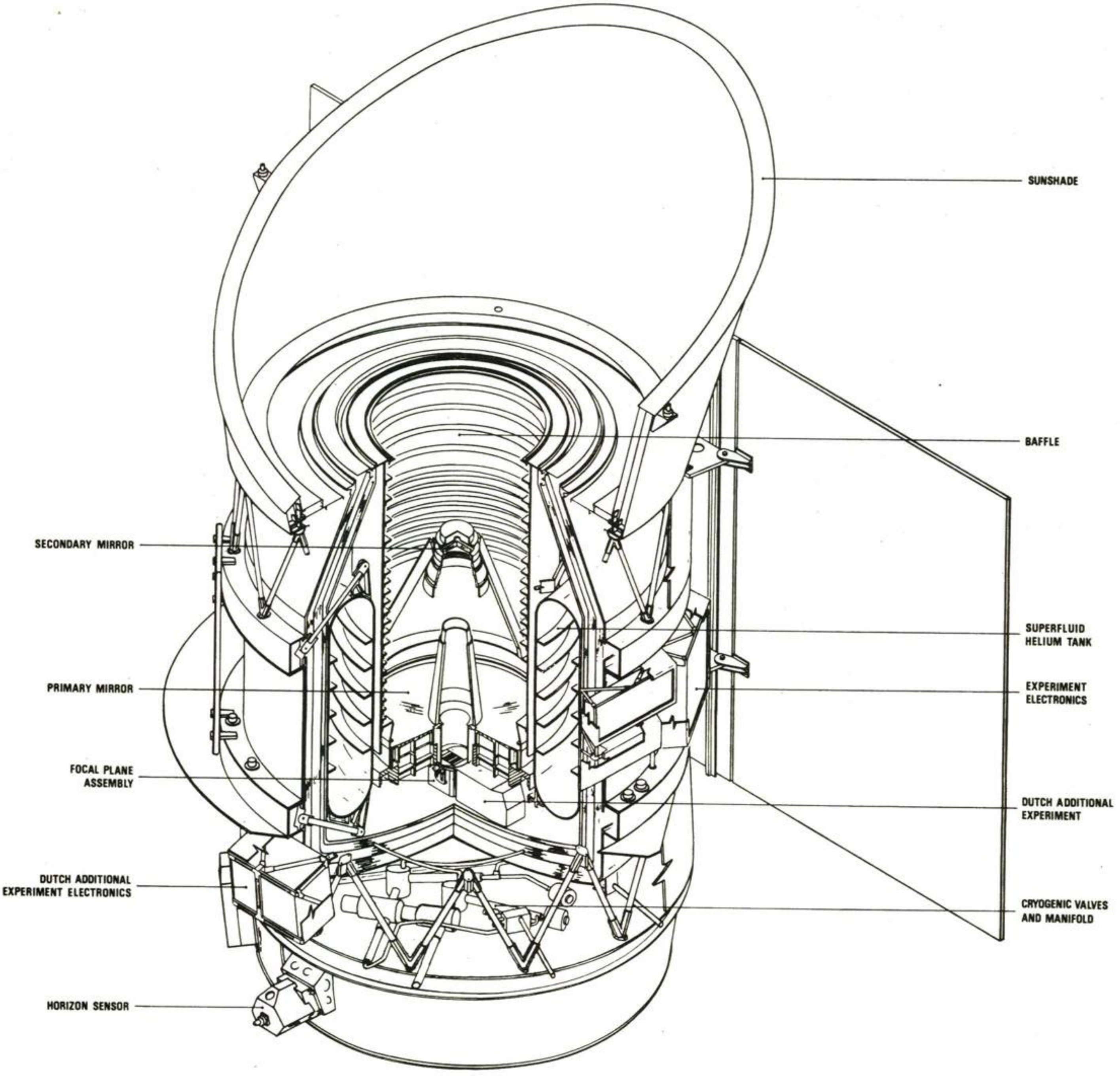
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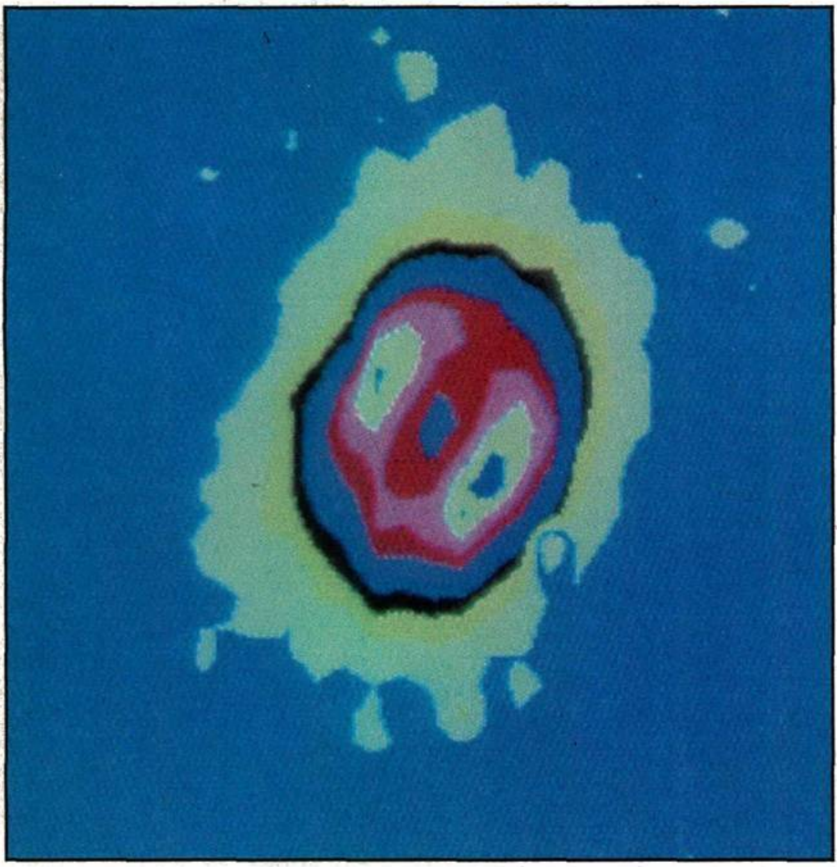
MISSION INVISIBLE

by Frithjof Sterrenburg

For millennia, astronomy was limited to the portion of the electromagnetic spectrum detected by the human eye — visible light. Analysis of other wavelengths in the spectrum began in the first decades of this century, when astronomers developed instruments capable of detecting radio waves from space. Other parts of the spectrum, however, are blocked by the Earth's atmosphere, so that ultraviolet, X-ray, gamma ray, and infrared astronomy had to await detectors that could be sent into orbit.

Space observatories have explored the ultraviolet, X-ray, and gamma-ray regions of the electromagnetic spectrum at fairly high resolution. But very cool objects like moons and asteroids don't radiate at these high energies. Similarly, many of the molecular transitions that take place in the cool gas of interstellar space emit low-energy long-wavelength radiation. Infrared (IR) astronomy can see the turmoil behind the dust of star-forming clouds, while radiation of shorter wavelengths is completely obscured. Furthermore, stars whose nuclear furnaces have not yet turned on emit far more long-wavelength radiation than visible light. Locating and studying these objects depends on high-resolution, high-sensitivity infrared surveys. In late January a Delta rocket launched a satellite designed for this very task — IRAS, the Infrared Astronomical Satellite.



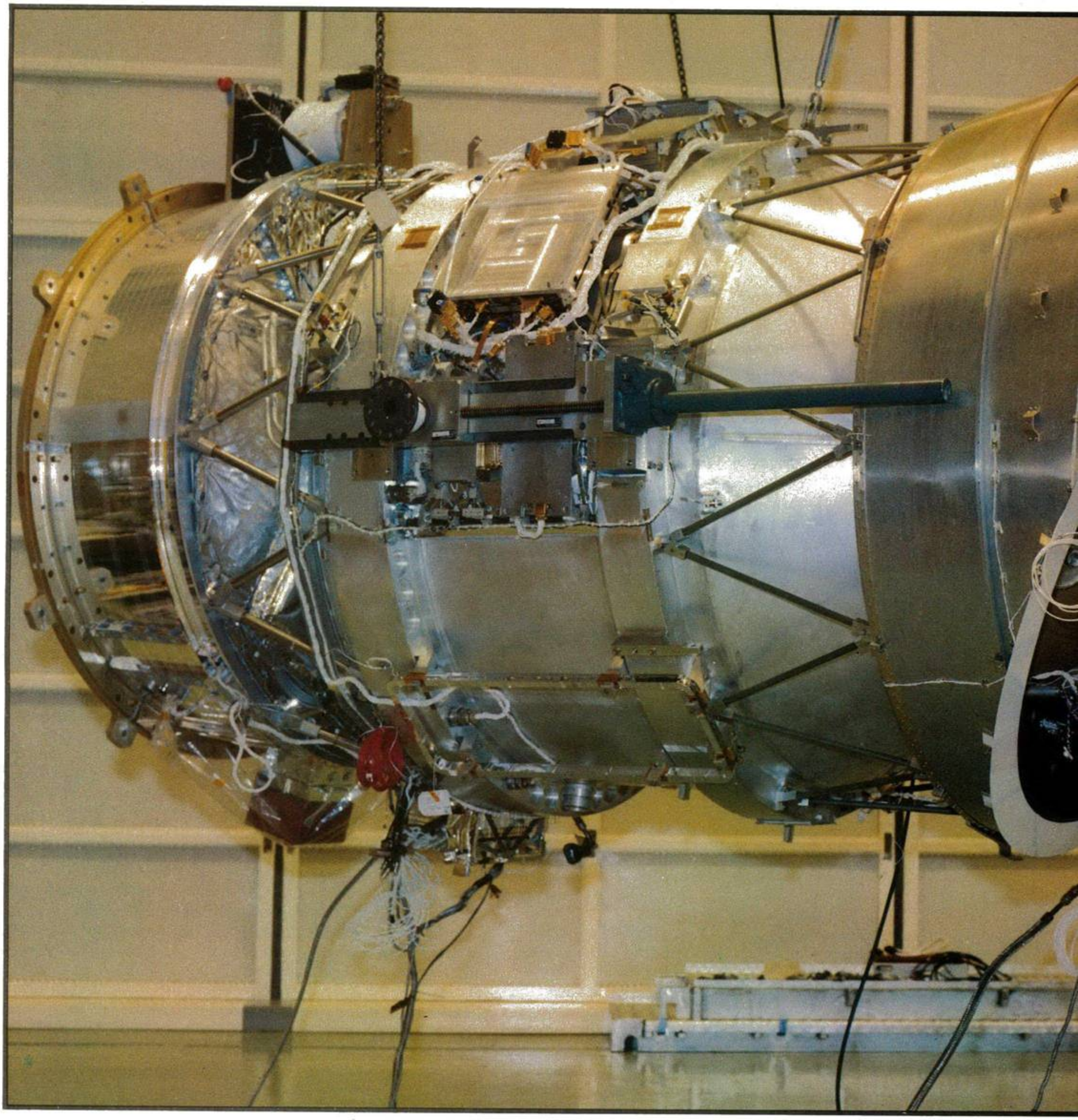
Infrared image of the planetary nebula NGC-7027. The picture is a computer reconstruction of infrared data at a wavelength of 20 microns. All IR images courtesy of Alan Bentley of the Wyoming Infrared Observatory.

A joint venture of the Netherlands, the United Kingdom, and the United States, IRAS has a price tag of about $180 million. Launched into a 600-mile-high "polar Sun-synchronous twilight orbit" — crossing the poles but straddling the day/night line — IRAS can look into space and use the Sun as both a power source and a standard reference. The craft's orientation can be controlled along all three axes with an accuracy of better than 20 seconds of arc. IRAS also has a powerful on-board computer that can be reprogrammed in orbit, a capability that saved a previous space mission. When the Netherlands launched its ANS ultraviolet satellite in 1974, a rocket malfunction placed the craft in an incorrect orbit. The new orbit would have seriously compromised the mission if the satellite's on-board computer could not be reprogrammed.

IRAS is about 3.5 meters long and weighs more than a ton. Along with the launch vehicle, the U.S. contribution to IRAS is its telescope — a Ritchey-Chretien Cassegrain telescope with a primary mirror 600 millimeters in diameter and a focal length of 5.5 meters. Since direct imaging — like the imaging on photographic film — is impossible, a battery of infrared detectors lies in the telescope's focal plane for alignment, spectrometry, and photometry. The range of wavelengths covered by the satellite is enormous: from 8 to 120 microns, or a factor of 15. In comparison, the spectral range detected by our eyes is less than a factor of 2.

Observations are made in various "modes." The *slow-scan* mode systematically sweeps the sky at a constant angular velocity. It can scan the entire sky at least twelve times a year, a redundancy that allows unwanted IR sources like space junk to be eliminated. In the *pointing* mode, the telescope points at the same celestial coordinates for a longer period in order to make protracted measurements. Detailed images can be obtained in the *raster-scan* mode, for which the satellite makes small oscillating motions. Since IRAS makes contact with a ground station only twice a day, it must store up to 12 hours of data on tape. Every 12 hours, when contact with the ground station is established, IRAS sends observational data and information on its own status to Earth and receives instructions for its next 12-hour observation period. In 7½ minutes, IRAS must send to a ground station a stream of data equivalent to the total contents of the Bible.

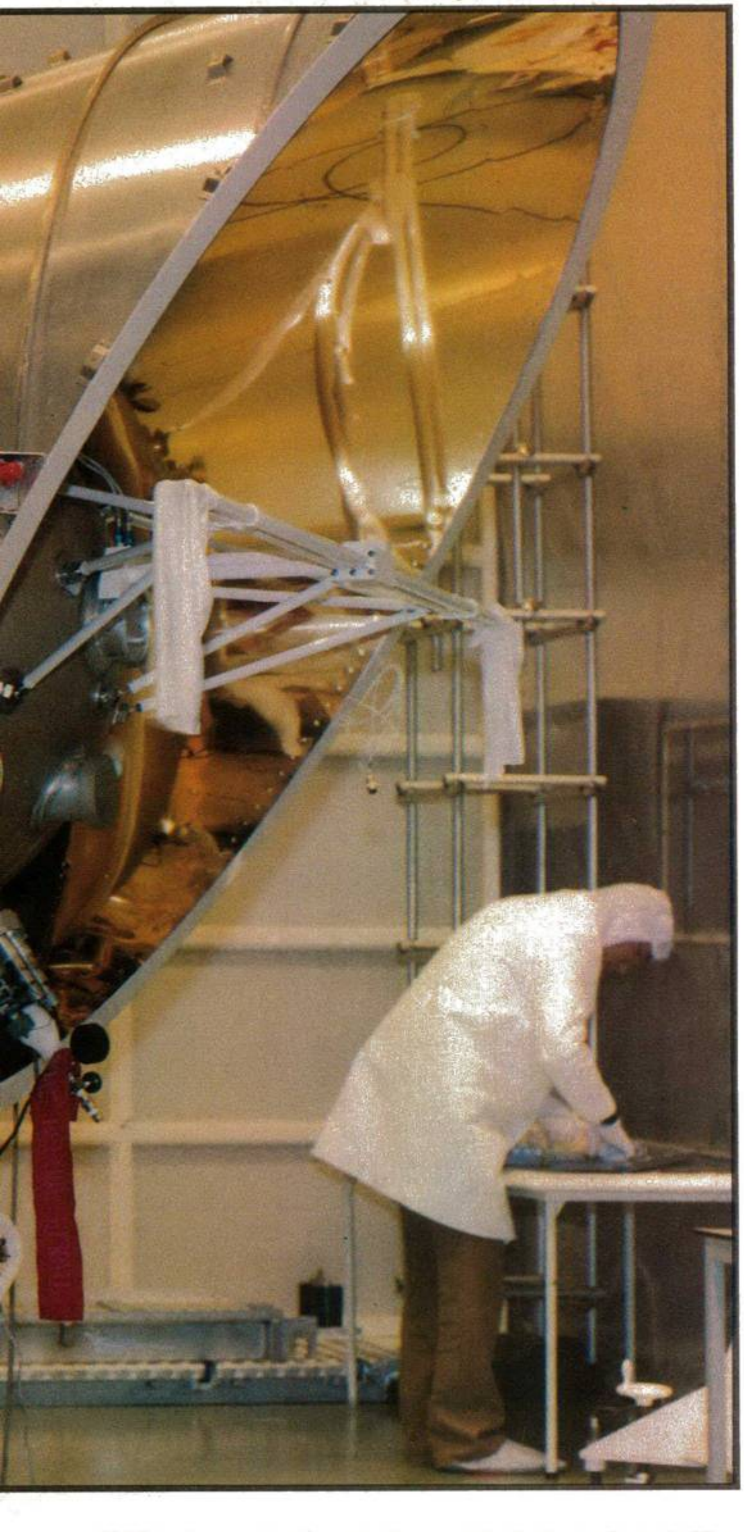
Early discussions of IRAS brought up the possibility of



decreasing this torrent of data — for example, by allowing the on-board computer to eliminate background noise. This would accelerate the "playback" from the data recorder. But the idea was eventually rejected. In the words of P. Wesselius of the University of Groningen, "This is the only IRAS, and you'll never know what you may have thrown away."

The construction and operation of the ground station is the United Kingdom's contribution to the mission. One interesting feature is the "quick look facility" designed for a preliminary analysis of the data. Researchers expect that IRAS will make many fundamental discoveries, and the ability to take a preliminary look at the data makes its operation extremely flexible. If the quick look reveals something interesting, astronomers can decide to make an immediate follow-up. The Jet Propulsion Lab at the California Institute of Technology will perform the final data analysis. This infrared survey of the universe is the first of its kind. To appreciate its importance, consider this: Astronomers have identified about 2,000 IR sources over the past 15 years, but IRAS can examine some 10,000 sources *per day*!

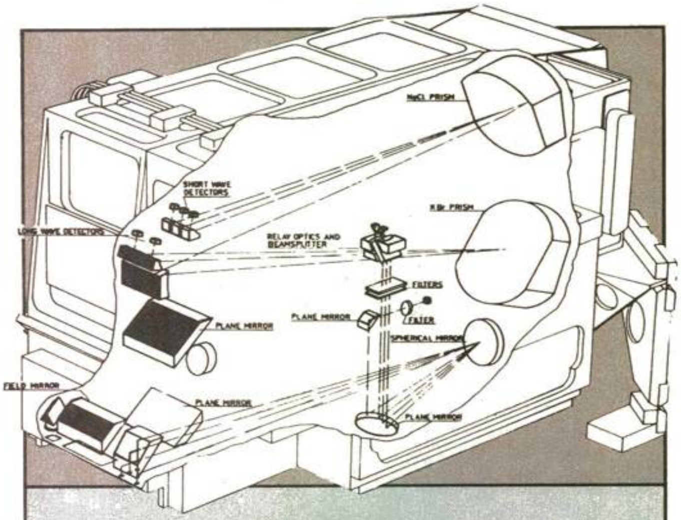
In a sense, IRAS is really two missions in one — a survey with its own follow-up. This built-in follow-up is part of the Dutch contribution (see box). While the survey instrument is intended to map the entire IR sky, IRAS carries three instruments for close scrutiny of selected objects: a low-resolution spectrometer and photometers for both long and short wavelengths. Together, these devices compose DAX (Dutch Additional Experiment). Whenever the survey discloses something particularly interesting, the operating schedule can be modified so that DAX can observe it in detail. According to W. Werner of the Institute of Physics in Delft, Holland, the original plan for DAX called for two



IRAS under construction. Engineers detected some irregularities during the satellite's final and most difficult test — 10 days in the space simulation chamber of the Jet Propulsion Laboratory. After minor adjustments, IRAS was shipped to California's Western Test Range for its January launch.

spectrographs using diffraction gratings. Instead of making two instruments with gratings, Werner's group made two prisms — one for long-wavelength and the other for short-wavelength IR. And instead of using flat surfaces, the prisms were made toroidal (doughnut-shaped) or spherical. "The prisms act as lenses in the image-forming system," Werner said. "This bit of trickery," he added, "meant that one instrument could replace the original two — so we added the photometers as extras."

Several objects were placed high on the DAX schedule even



Designing DAX

Optical instrumentation for the Dutch Additional Experiment (DAX) was the responsibility of W. Werner, head of the department of geometrical optics at the Institute of Applied Physics in Delft. The department is paradise to an amateur astronomer; its atmosphere is one of unabashed enthusiasm.

The original plan for DAX called for two spectrographs using diffraction gratings — two instruments were necessary in order to cover the spectral range involved. But Werner's group thought the design could be improved. "In general," said Werner, "we always try to do better." In this case, the group proposed using prisms instead of diffraction gratings and using the prisms themselves as part of the image-forming system. For proper spectral coverage, two prisms were used: one of potassium bromide (KBr) for long-wave IR and sodium chloride, or common table salt (NaCl), for short-wave IR. KBr and NaCl are crystalline substances that are difficult to grind and subject to weathering — yet despite the delays in construction of the telescope, the prisms are still up to specification. By using two prisms on one spectrograph instead of the two spectrographs originally specified, Werner's group saved enough space to add in two photometers.

Werner's optics department decided to start early with their design, and this caused unique problems. "The design of the telescope kept changing," Werner said, "and there came a time when we didn't have the faintest idea where the image plane was going to be located." So what did the department do? "We made a series of drawings showing solutions for various sizes of telescope," Werner recalled, "and presented them as 'the Institute of Applied Physics's new spring spectrograph catalog'!"

K.J. Wildeman, project leader for hardware at the University of Gronigen's Space Research Group, was faced with the odd behavior of electronics near absolute zero. "Operations at cryogenic temperatures caused terrifying problems," he recalled. "One major problem was excessive noise. Thermal noise is reduced by cooling," Wildeman said, "but static electricity kept ruining transistors in the amplifiers." The transistors, called MOSFETs, also showed *latch-up*, assuming a condition from which they would not return — a sort of electronic catatonia. "Nevertheless, we stuck to MOSFETs — not because we thought they were better," he said, "but because to redesign them at that stage would have caused a serious delay." The problems were solved by carefully selecting the MOSFETs, and DAX was completed on schedule. In the U.S., however, the same problems led to the decision to switch to another type of transistor, called JFETs, which contributed to a delay of about a year.

About a light-year behind the Orion Nebula lies a cluster of infrared sources known as the Becklin-Neugebauer Kleinman-Low complex. The IR emission may arise from stars just a few thousand years old. The bright circle appears to be an OB-type star obscured by dust.

The central star of S 106 blows ionized gas out along the rotational axis of a surrounding cloud of gas and dust. Infrared work reveals the hot central star (blue circle, center) and several dusty "hot spots."

Imaging the Infrared

Photographic emulsions are insensitive to the wavelengths where most infrared observations are made — from about 2 to 20 microns. In order to record an image, the intensity of each picture element, or *pixel*, must be measured by an infrared photometer; then all the measurements must be combined.

One problem is that the spacing between pixels may be far smaller than the pointing accuracy of the telescope. To get around this limitation, IR telescopes are designed with wobbling secondary mirrors that flip back and forth between the source and the sky background. The wobbling mirror allows astronomers to determine the intensity of the clear sky, which will be subtracted from the measured intensity of the source. Also, the telescope's pointing angle can be changed very accurately when the secondary's wobble is computer controlled.

To produce these images, astronomers at the Wyoming Infrared Observatory used a 92-inch telescope with a secondary that can wobble up to 10 times a second. The brightness of each pixel is then fed into a computer and displayed on a television screen, where it can be photographed. Blue, green, or red colors label the data from each of the three wavelengths displayed in these images.

before launch — like the galactic center and the extremely young stars in the Orion Nebula. The total Dutch contribution (satellite vehicle, DAX, on-board computers, software development, transmitters and receivers, attitude control, and more) originally amounted to about half the total estimated cost. All systems were delivered on schedule and several million dollars below the estimate.

There were, however, serious problems with the U.S. telescope and its associated electronics, that resulted in a delay of about a year and almost doubled its cost. The telescope is fairly straightforward. It "sees" heat energy rather than light, and does so with extreme sensitivity — it can detect the heat of a flashlight bulb 2,000 miles away. Everything in space absorbs energy from the Sun and radiates it away as heat, but for IRAS this means that the satellite itself would become "red hot" to its own eyes. So the telescope, detectors, and the associated amplifiers must be cooled to almost absolute zero (-273° C). Up until now, electronic hardware in space has operated at room temperature, according to P.F. Linssen of the Netherlands Agency for Aerospace Programs. The behavior of electronics cooled to absolute zero was totally unknown before IRAS, and engineers encountered an assortment of unpredicted, scientifically interesting phenomena that made the equipment completely useless. "The nature of the problem can be understood," Linssen said, "if you remember that solid-state electronics depends on *semi*-conduction, whereas one of the phenomena seen at these extreme temperatures is *super*-conduction." The problems were solved, but only after long delays and escalating costs.

Another consequence of the need for cooling is that IRAS has a limited lifetime. Its 70 kilograms of superfluid helium should last for 200 days; when the coolant runs out, IRAS will rapidly warm up and become insensitive to faint sources.

Although IRAS is an interesting piece of hardware in itself, it is after all an astronomical instrument. What do astronomers hope to see with it? According to Boudewyn Baud of the Space Research Group of Groningen University, IRAS will give astronomers a new look at stars in the making. "One of the things we hope IRAS will show," he said, "is a star that is being born." Astronomers have found very young stars within molecular clouds, but their visibility means that early infancy is already behind them. "What IRAS might show is a star that has not yet ignited its nuclear fires and is still in the process of formation, wrapped in clouds of material — and therefore optically invisible," Baud said. "Follow-up studies of spectral lines would reveal the motions of the material surrounding the star."

The core of our Galaxy is another prime candidate for the spacecraft's infrared eyes. Both radio and IR can penetrate the gigantic clouds of gas and dust that hide the core from view in the optical spectrum. While astronomers have already detected some core objects using Earth-based IR techniques, they believe IRAS will give an unprecedented look at the Galaxy's center.

All in all, IRAS is an important first — both for the participating nations and the astronomical community. "There are nine U.S., six Dutch, and three British astronomers in this project, and the scientific level is high indeed," said Reinder van Duinen, director of Fokker's Space Division, one of the companies responsible for building IRAS. "Of course, having a beautiful scientific project is not sufficient motivation to start spending the money involved in IRAS," he added, "but without an excellent scientific program you haven't a hope of ever building a tool like it!" In its 200 days of operation, IRAS will give astronomers their first detailed look at the infrared universe. The scientists expect a few surprises, but they just may get a revolution.

Frithjof Sterrenburg is an amateur astronomer who lives in the Netherlands. His most recent article for ASTRONOMY was "A Westerbork Decade" (November 1982).

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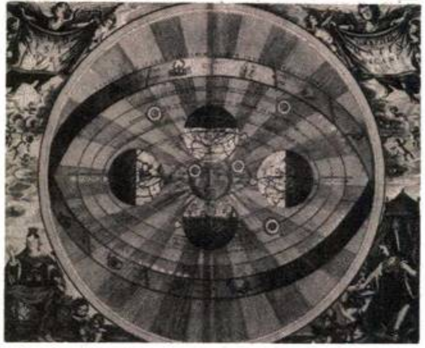

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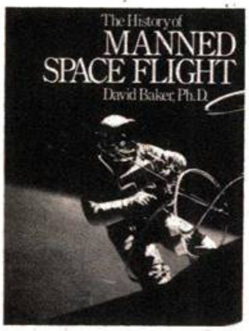

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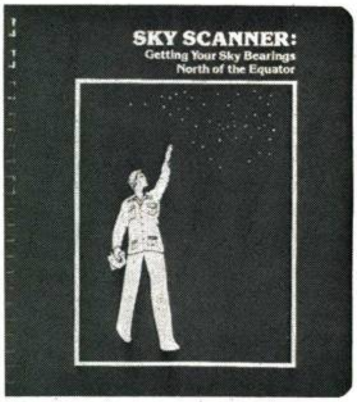

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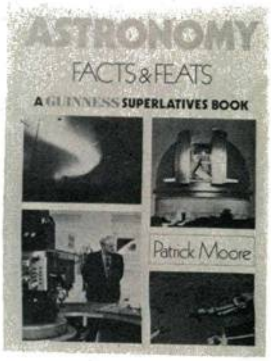

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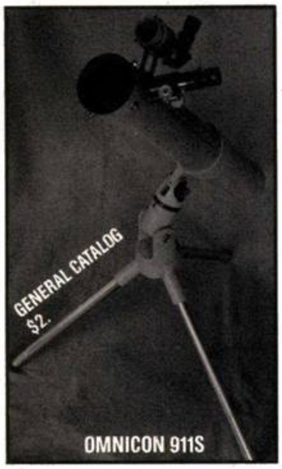

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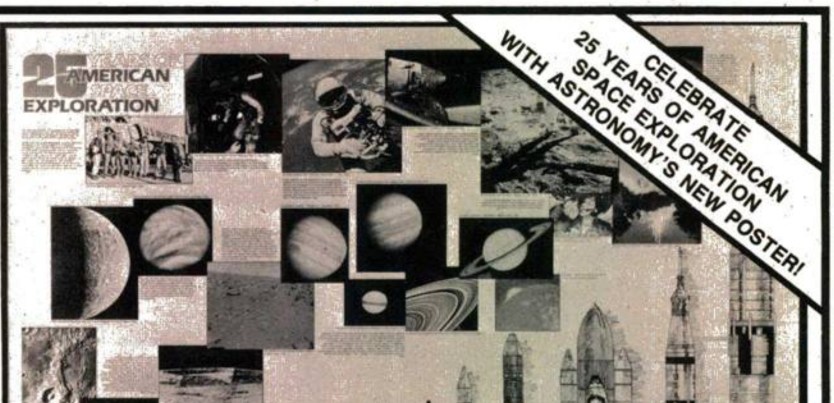
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ANNOUNCEMENT — The 13th annual conference of the Science Fiction Research Association will be held in Midland, Michigan, June 9 to 12, 1983. The theme will be "Science Fiction: Arts and Sciences." Contact Dr. Joseph W. DeBolt, Department of Sociology, Central Michigan University, Mount Pleasant, MI 48859. Phone (517) 774-3422 or (517) 773-9764.

ANNOUNCEMENT — Newsletter editors, send a copy of your astronomical newsletter, with your name and address, for inclusion on a nationwide mailing list. Enclose SASE for your copy of the finished product. Contact Astronomical League Newsletter Directory, 7117 Misty Meadow Drive, So., Fort Worth, TX 76113.

ANNOUNCEMENT — The Central Florida Astronomy Society invites interested persons to attend their monthly meetings the second Wednesday of each month at the John Young Science Center, Orlando, Florida. Contact Bob Perry, 1624 Les Court, Kissimmee, FL 32741. Phone (305) 933-1682.

ANNOUNCEMENT — The Christian Astronomical Research Administration is an international fellowship of "born again" Christians who have a vision of ministry: using their interests in astronomy to glorify the triune God. Contact Christian Astronomical Research Administration, Box 943, Morton Grove, IL 60053.

ANNOUNCEMENT — The Astronomical Society of Kansas City meets on the fourth Saturday of each month. Meetings start at 7:30 p.m. in room 103 of Haag Hall Annex at the UMKC campus. The annex is located between Rockhill Rd. and Holmes on 52nd St. For information phone Gary Pittman, (816) 229-2677.

ANNOUNCEMENT — The Amateur Astronomers Association of Pittsburgh meets on the second Friday of every month at Buhl Science Center, Allegheny Observatory, or Beachwood Farms. Regular star parties and observing sessions are scheduled. Contact Art Glaser (412) 341-5862, Dave Smith (412) 531-8185, or Gordon Jenkins (412) 787-5948.

ANNOUNCEMENT — The Plutonian Society is offering pros, amateurs, and rookies the opportunity to join a nationwide network of stargazers. Drop us a line — you won't be sorry! Contact Bert New, Rt. 3, Box 836, Valdosta, GA 31601.

ANNOUNCEMENT — Progressive Space Forum is the only organization formed specifically to oppose the militarization of space and promote international cooperation. Members throughout U.S. and other countries. Bimonthly newsletter, activities bulletin; sample issue $1. Free brochure. Contact Progressive Space Forum, 1476 California, San Francisco, CA 94109.

ANNOUNCEMENT — The Chicago Astronomical Society will be hosting Astrofest for the fourth consecutive year. Astrofest 83 will be held from Friday, September 30 through Sunday, October 2, 1983, at Camp Saw-waw-nas-see (the same site as last year). Camp Saw-waw-nas-see is a 4-H camp located near Kankakee, Illinois. For further information, contact Astrofest, P.O. Box 956, Tinley Park, IL 60477.

ANNOUNCEMENT — Join other amateurs who are actively participating in the field of amateur radio astronomy! The Society of Amateur Radio Astronomers (S.A.R.A.) can assist you. Contact S.A.R.A., 4940 Woodhurst Way, Stone Mountain, GA 30088.

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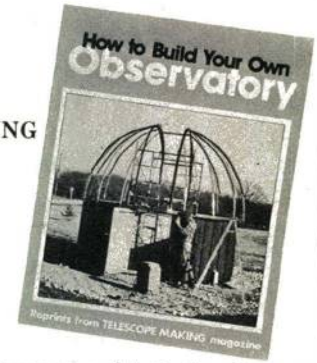

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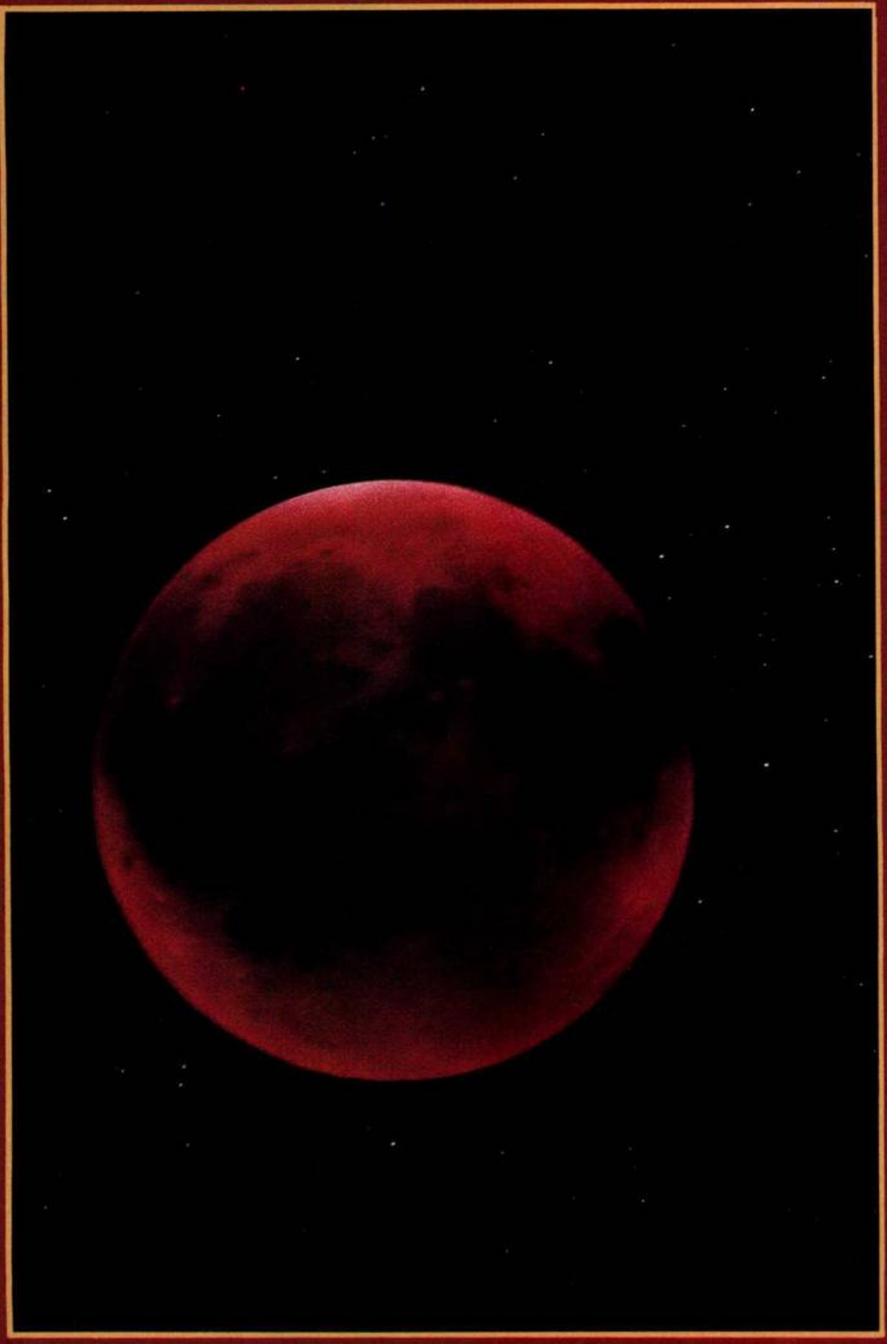
december's dark lunar eclipse

photography in astronomy



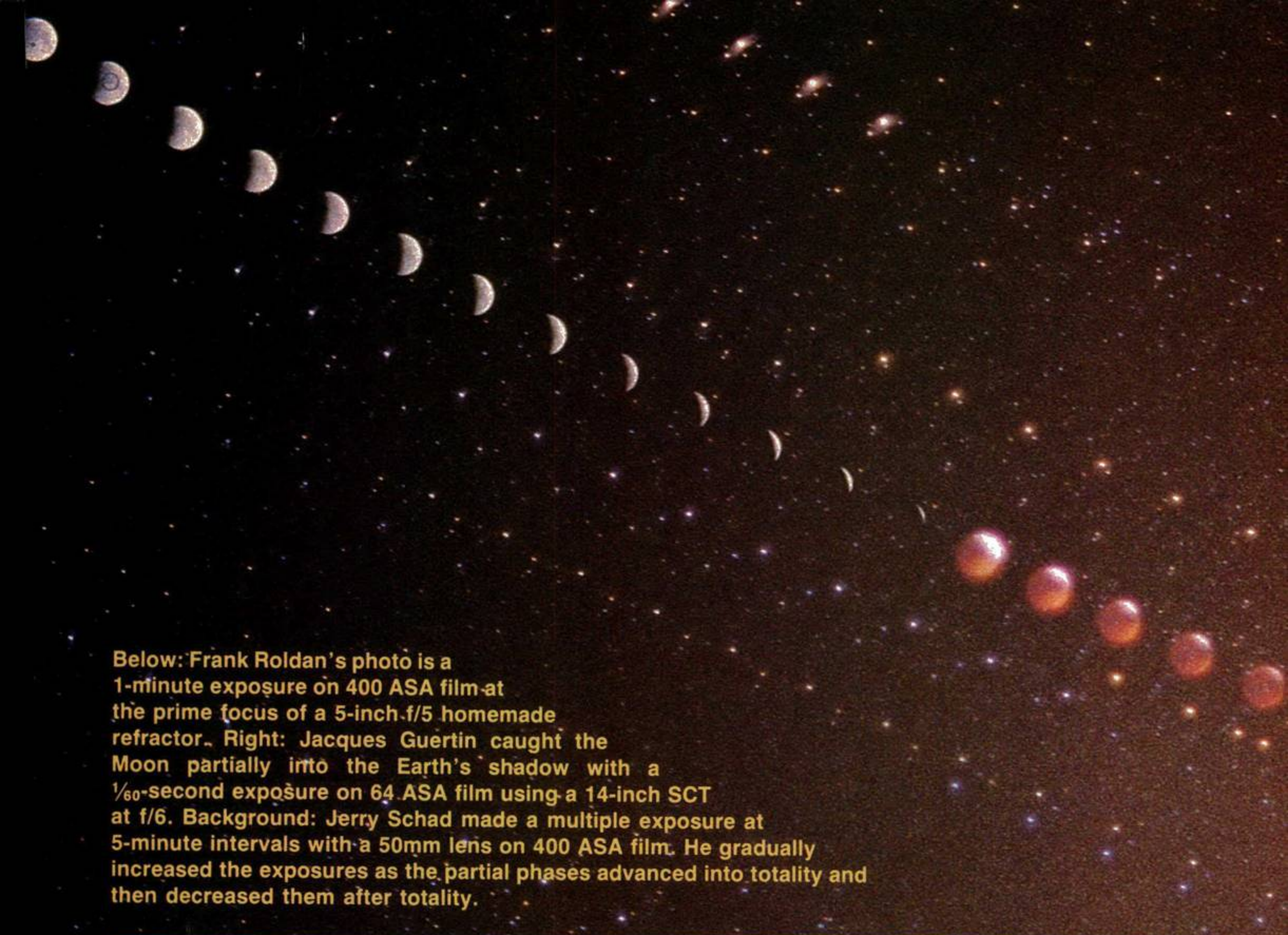
At the last Full Moon of 1982 on December 30th, viewers across all of North America were treated to a superb lunar eclipse, in some ways reminiscent of the one that occurred the previous July.

Though shorter in duration because the Moon did not pass as centrally through the Earth's shadow as it did in July, this eclipse seemed to most observers to look as dark or even darker — perhaps a lingering gift of the El Chichon volcanic eruption. In addition, both eclipses featured a darkened Moon surrounded by a rich starfield: in July, the Moon lay near Sagittarius and the center of the Milky Way, while in December, the field was the scarcely less rich part of the Milky Way that runs through Gemini.

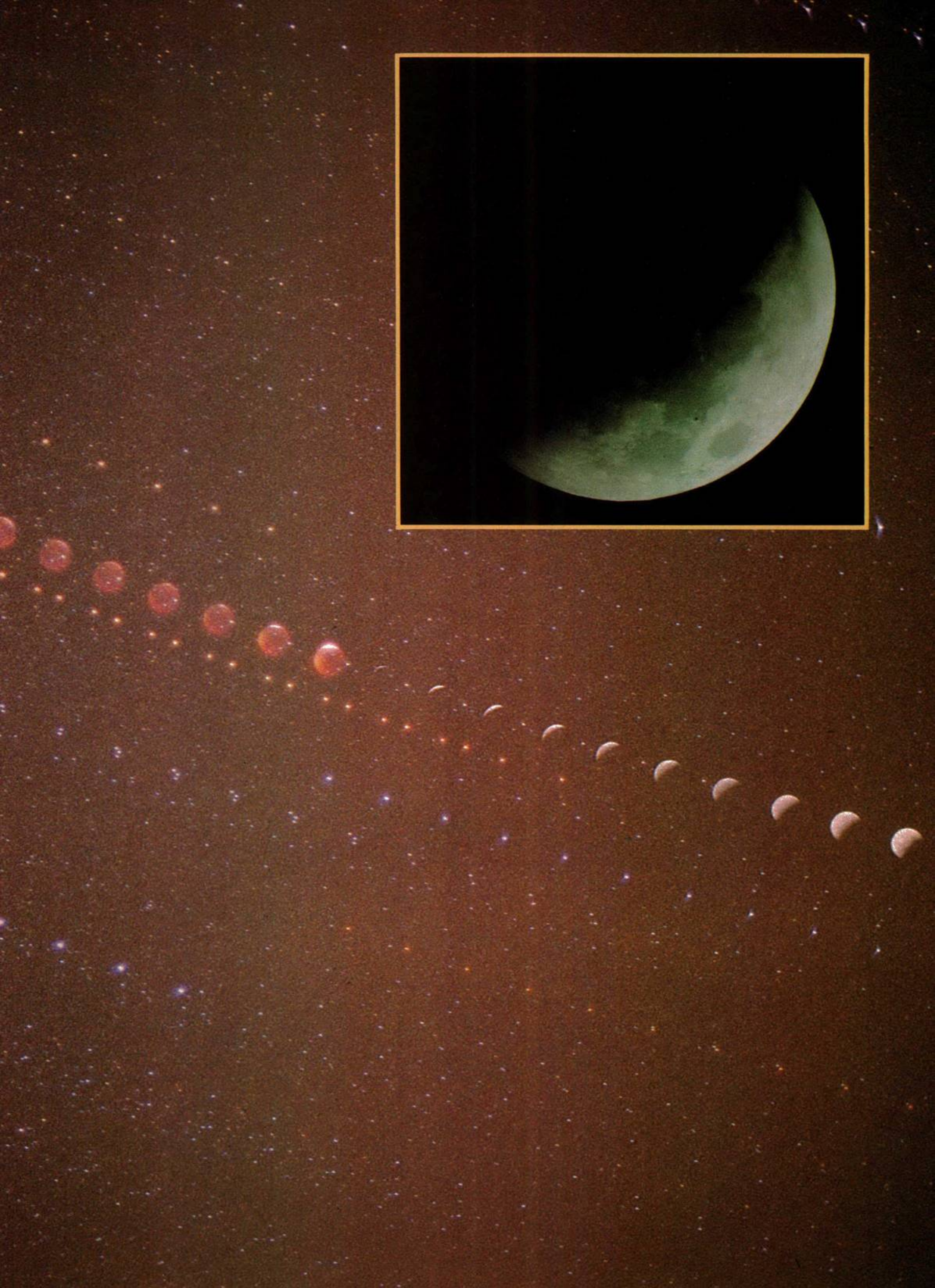
For East Coast observers, the event took place close to moonset as the morning Sun was about to rise. For observers who were farther west across the continent, the eclipse came earlier, with the Moon's elevation correspondingly higher. On the West Coast, the Moon was well up in the southwestern sky at mid-eclipse, and observers could follow the entire sequence from first penumbral contact to last in a dark sky.

All in all, it was a fine show to remember, as the photos on these pages (a fraction of what poured into ASTRONOMY's offices) amply testify. Interestingly, if the photos submitted are a guide, comparatively few observers photographed the partial phases — a favorite in years past — while a great many took long-exposure photos showing the eclipsed Moon surrounded by stars. But whatever photos they took, those who ventured out into the cold were well repaid with souvenirs of a celestial event that won't be repeated over all of North America until August 16, 1989.

Jack and Carla Gibbons photographed the totally eclipsed Moon with a 1-minute exposure (guided on the background stars), using hypered 400 ASA film in a 12.5-inch f/5 telescope.



Below: Frank Roldan's photo is a 1-minute exposure on 400 ASA film at the prime focus of a 5-inch f/5 homemade refractor. Right: Jacques Guertin caught the Moon partially into the Earth's shadow with a 1/60-second exposure on 64 ASA film using a 14-inch SCT at f/6. Background: Jerry Schad made a multiple exposure at 5-minute intervals with a 50mm lens on 400 ASA film. He gradually increased the exposures as the partial phases advanced into totality and then decreased them after totality.



the backyard astronomer

ursa major

Mercury

Mercury will appear low in the western sky after sunset before April is a week to 10 days old. Around the 10th, Mercury's disk will be 6″ of arc in diameter and 75% lit. Greatest eastern elongation occurs on the 21st, essentially simultaneously with the planet's highest elevation: 11°, 45 minutes after sunset, at azimuth 288° (west-northwest). After greatest elongation, you'll see the planet grow larger and slightly brighter, and its phase will shrink to a crescent. By the end of April, it will be about 7° high, 10″ of arc across, and only 15% lit.

A rising Mercury will pass close by a descending Mars on the evening of April 9th, but the 1.3° separation between them means that only low powers or an RFT will place the two in the same field of view. On the 14th, look for a very slender Moon to the left of Mercury.

Venus

During April, Venus will just about reach its maximum elevation in the evening sky for this apparition. It will continue to climb a bit in early May, but thereafter it will make a fairly rapid descent, disappearing into the solar glare by early August. The Moon will be near Venus on the 15th and 16th.

Venus' disk will be 13.3″ of arc across and 81% lit on April 1st; these values will change to 15.7″ of arc and 71% lit by the 30th. Venus is a brilliant object, and you may find that observing before twilight has fully deepened into night is preferable — otherwise, the contrast between Venus and the sky is so great that you lose a sense of crispness in viewing the planet.

Mars

Mars is virtually out of sight in the evening sky. It has its meeting with Mercury on the 9th, but that's about the last you'll see of it.

Surrounding Gamma Cygni (left center), a second-magnitude star in the middle of Cygnus, are banks of nebulosity, dust, and young stars. Paul Roques's photo — this month's "Best Astro-Photo" award winner — was taken on 2415 film with a 30-minute exposure, using a 4-inch f/2.6 Schmidt camera.

Asteroids

1 Ceres (magnitude 8.7) is in central Capricornus. Its positions:

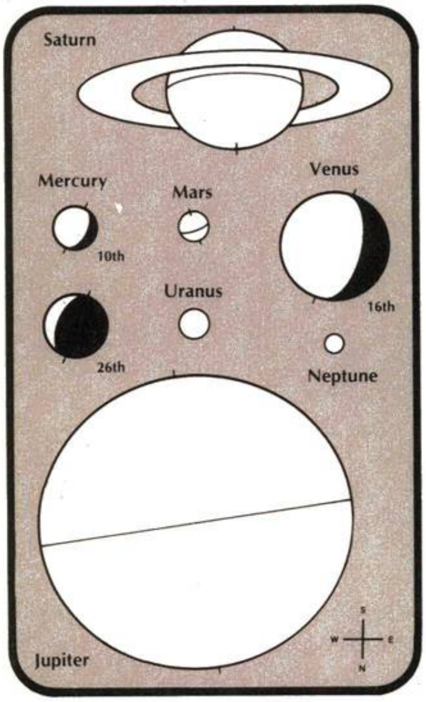
9th: 21h 18m 02s, −21° 46.9′
19th: 21h 30m 28s, −21° 21.4′

Ceres rises around 3 a.m. local time at mid-month.

2 Pallas (9.9) lies in northwestern Aquila. Its positions:

9th: 19h 12m 45s, +13° 59.0′
19th: 19h 17m 24s, +15° 37.2′

Pallas rises around local midnight on the 15th.



3 Juno (10.4) lies in central Aquarius. Its positions:

9th: 22h 50m 29s, −3° 19.0′
19th: 23h 07m 28s, −1° 55.3′

Juno rises just before 4 a.m. local time at mid-month.

4 Vesta is in conjunction with the Sun on April 14th — it will be out of sight all month.

To facilitate plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.

Jupiter

Jupiter rises around 11 p.m. local time in mid-April and crosses the meridian about 3:15 a.m. It lies in Scorpius, a little to the northeast of first-magnitude Antares. Toward the end of April, Jupiter will be 4.5 astronomical units (670.5 million kilometers) distant. Its equatorial diameter at this time will be 44″ of arc — close to the maximum for this apparition. By the time of opposition in late May, it will have gained only 1.4″ of arc more.

Saturn

The ringed planet reaches opposition this month at 19h UT on the 21st, about an hour before Mercury reaches greatest eastern elongation. Saturn is moving retrograde in Virgo, some 10° east of Spica, and will be visible in the east as the sky becomes dark.

At opposition, Saturn's apparent size will be 19″ of arc (equatorial) by 17″ (polar). The rings, which are tipped 16° to our line of sight, will spread 42.8″ across in an almost exact east-west direction.

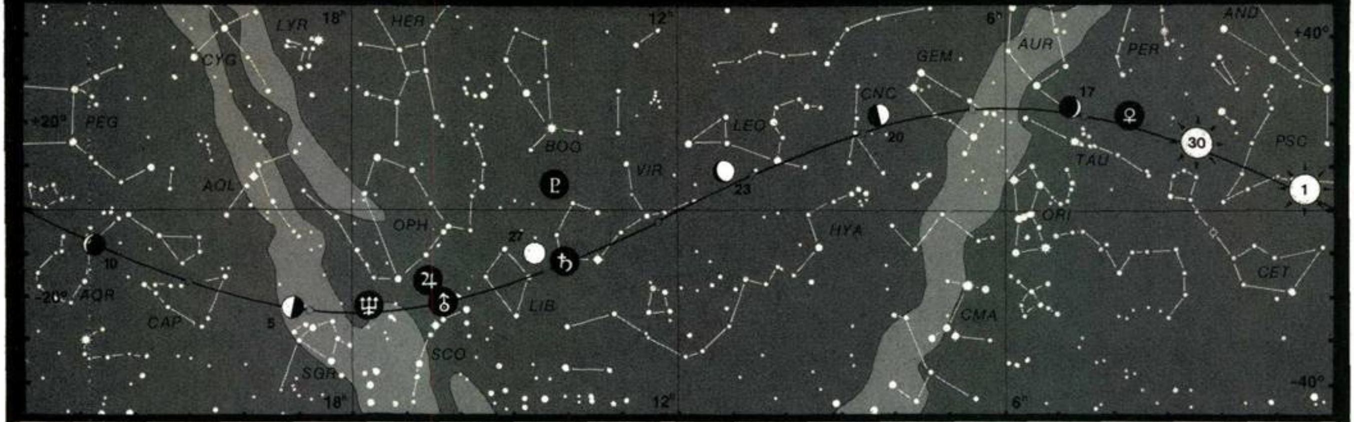
Uranus

Uranus will rise into view in the eastern sky by about 10:30 p.m. local time in the middle of the month. Though faint (5.8 magnitude), it is easy to locate, being 4.5° north of Antares. Use a low-power eyepiece to sweep north from the star, and then switch to a medium or high-power ocular when you've found it. Uranus has a disk that measures 3.8″ of arc in diameter.

Neptune

Farther to the east than Uranus, Neptune rises later on the 15th — around local midnight. The planet lies in Sagittarius, a short distance to the northwest of the Trifid Nebula, M-20. Scan a degree north of the nebula and then a little over a degree west. Neptune has a

planetary data april 1983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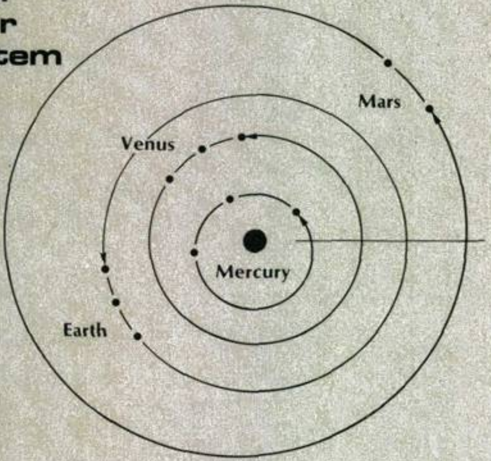
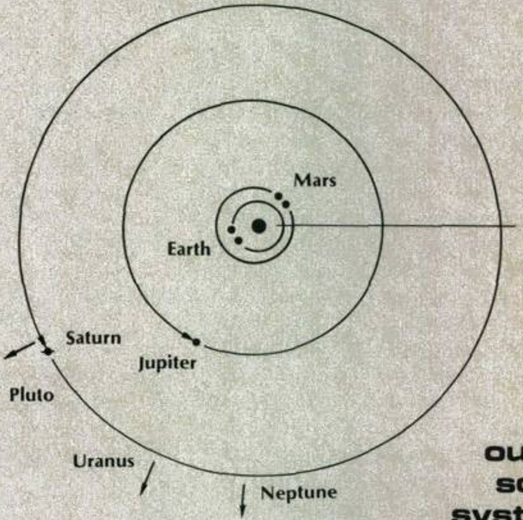
inner solar system


Mars
Venus
Mercury
Earth


Mars
Earth
Saturn
Jupiter
Pluto
Uranus
Neptune

outer solar system

				Angular	%	Distance (AU) from:		Longitude:			
		Date	Mag.	Size	Illum.	Earth	Sun	Heliocentric	Ecliptic	R.A. (1983.3)	Dec.
Sun		1	−26.7	32.1′	—	1.00	—	—	10°42.5′	0h 39.3m	+4°14.1′
		15	−26.7	31.9′	—	1.00	—	—	24°28.5′	1h 30.6m	+9°28.9′
		30	−26.7	31.8′	—	1.01	—	—	39°06.2′	2h 26.8m	+14°31.7′
Mercury	☿	1	−1.6	5.1″	97%	1.30	0.32	34°49.7′	16°03.0′	1h 01.4m	− 6°06.8′
		15	−0.4	6.6″	61%	1.02	0.32	120°39.8′	42°04.4′	2h 38.2m	+17°38.9′
		30	+1.5	9.8″	15%	0.68	0.40	190°43.7′	54°46.4′	3h 29.7m	+21°34.4′
Venus	♀	10	−3.5	13.9″	78%	1.21	0.72	111°37.5′	55°25.2′	3h 33.1m	+20°21.3′
		30	−3.6	15.7″	71%	1.08	0.72	144°06.7′	78°45.9′	5h 12.5m	+25°05.7′
Mars	♂	15	+1.6	3.9″	100%	2.43	1.46	45°30.6′	36°30.5′	2h 18.6m	+13°46.0′
Jupiter	♃	15	−2.0	42.6″	100%	4.62	5.37	242°42.1′	249°56.9′	16h 35.8m	−21°05.8′
Saturn	♄	15	+0.4	19.0″	100%	8.77	9.77	210°54.4′	211°10.5′	14h 01.8m	−9°28.1′
Uranus	♅	15	+5.8	3.8″	100%	18.21	18.94	246°34.7′	248°12.9′	16h 27.9m	−21°37.9′
Neptune	♆	15	+7.7	2.5″	100%	29.83	30.27	267°28.1′	268°42.7′	17h 56.5m	−22°11.2′
Pluto	♇	15	+13.7	0.2″	100%	28.94	29.89	208°07.4′	207°47.1′	14h 09.3m	+5°34.7′

moon data

Last Quarter	April 5 at	8:38
New Moon	April 13 at	7:58
First Quarter	April 20 at	8:58
Full Moon	April 27 at	6:31
Last Quarter	May 5 at	3:43
New Moon	May 12 at	19:25

Apogee: April 6 at 18h......404,439 km.
Perigee: April 21 at 8h......369,748 km.

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times in The Backyard Astronomer are UT unless otherwise noted. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 hours UT on February 2, then EST for the event is 10 p.m., February 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m, March 4.

Jupiter and Saturn were photographed the *same night last May* by Rick Kurczewski and Gary Romans. The equipment they used to take both photos was a 16-inch Newtonian with *eyepiece projection* to a focal length of f/87 and 400 ASA film. The exposure for Jupiter was 1 second; for Saturn, 2 seconds.

magnitude 7.7 disk 2.5″ of arc across.

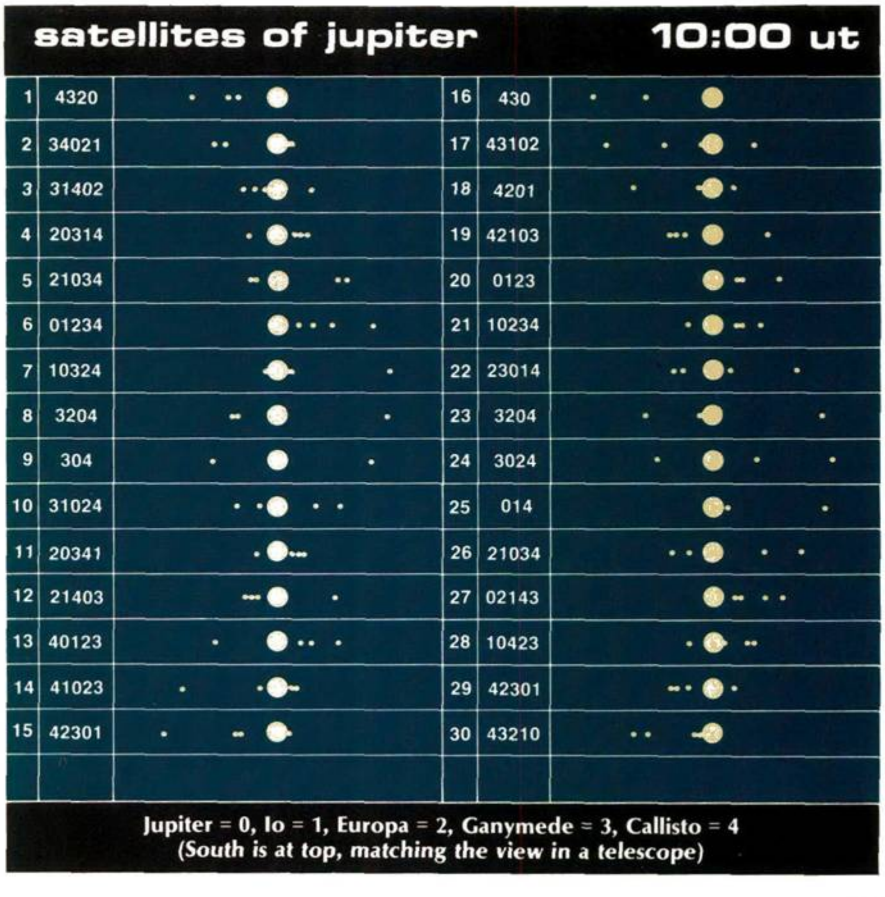
Pluto

At oppostion on April 18th, Pluto will lie 28.9 AU (4,306 million kilometers) distant, its magnitude 13.7. This theoretically places it in reach of telescopes having 8 inches or more aperture, but many observers have been able to spot it initially only with the help of somewhat larger scopes.

The planet lies 3° north and about 20′ west of the star CU Virginis, which is shown near the center of chart 14 of the *Sky Atlas 2000*. This star is also plotted (though unlabeled) on chart IX of the old *Atlas of the Heavens [Atlas Coeli]*. CU Vir is the 4.5 magnitude dot two centimeters to the upper left of Tau (τ), near the center of the chart.

Meteors

The main annually recurring shower for April is the Lyrid, which reaches peak activity on the morning of the 13th. The display in most years is only so-so (zenithal hourly rates of 10 to 20). But last

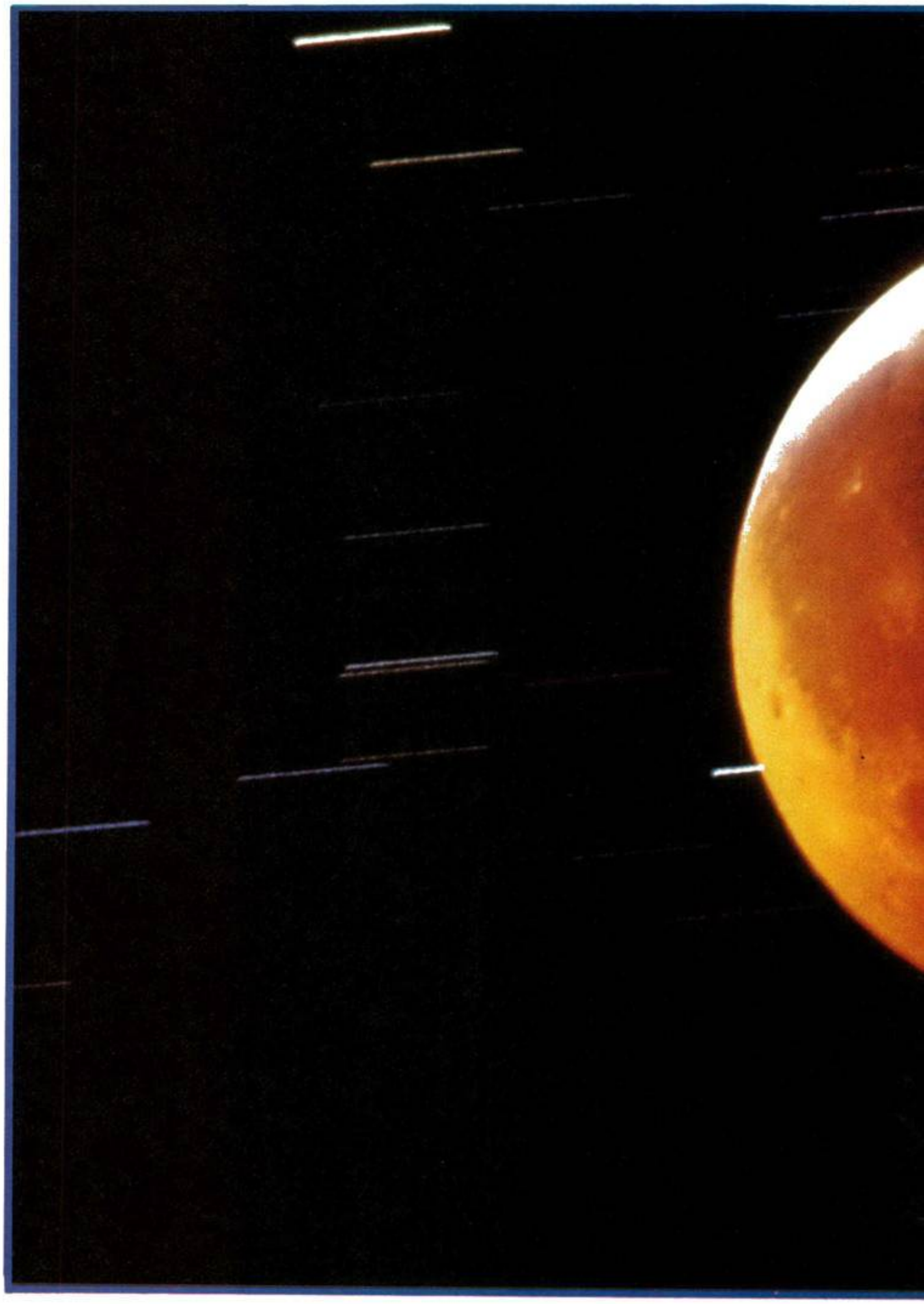


satellites of jupiter 10:00 ut

1	4320	16	430
2	34021	17	43102
3	31402	18	4201
4	20314	19	42103
5	21034	20	0123
6	01234	21	10234
7	10324	22	23014
8	3204	23	3204
9	304	24	3024
10	31024	25	014
11	20341	26	21034
12	21403	27	02143
13	40123	28	10423
14	41023	29	42301
15	42301	30	43210

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

Many astrophotographers guided their lunar eclipse photos on the stars, but Tom Greska guided on the Moon for 12 minutes — and came away with a crisp photo of the lunar disk surrounded by colored startrails. His telescope was a homemade 8-inch f/6 Newtonian; the film used was 200 ASA.



year's display was superb — over 100 per hour at times. The shower may be one like November's Leonids in that it has peak years in which the rate jumps dramatically. In any event, keep your eyes on Lyra during the night of the 12th-13th. (The Moon will be near First Quarter and will set after midnight.)

close-up on ursa major

The season for observing is returning, bringing warmer temperatures and busier telescopes to northern-hemisphere viewers of the heavens. As it happens, springtime is the season for galaxies; when the winter Milky Way sets and the summer Milky Way returns, a huge block of sky relatively free of our Galaxy's obscuring gas and dust presents itself. Thus it is the best time to look out of our neighborhood, far away to those other huge aggregations of stars, gas, and dust.

Few areas of the sky are richer in galaxies than **Ursa Major**, making the Big Dipper a prime target area for springtime hunting. Of course, the region also includes other objects — double stars, variable stars, and a few planetary nebulae — but galaxies are the predominant celestial attraction.

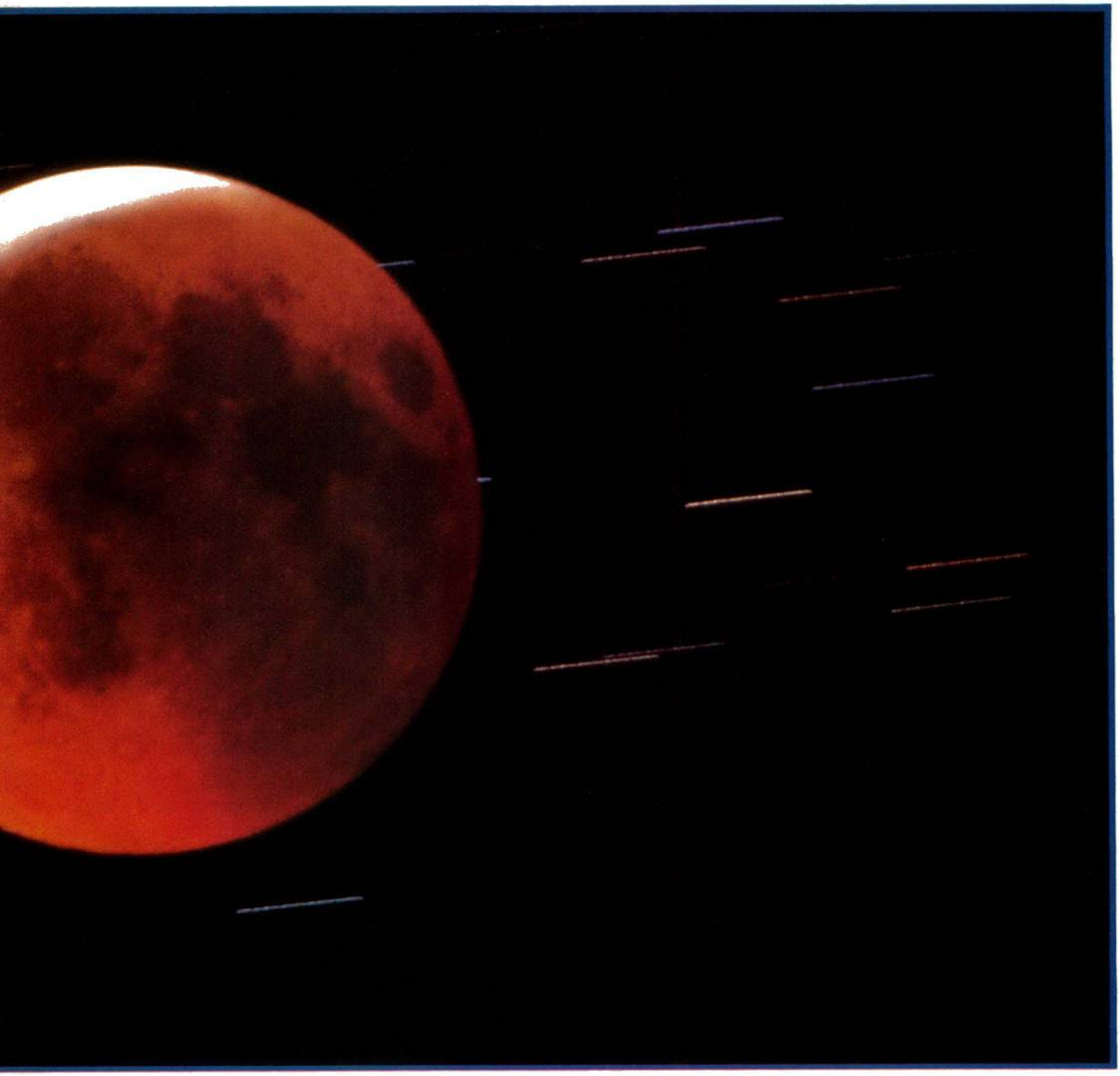
The two most commanding such objects — M-81 and M-82 — form an interacting system. **M-81** is a huge Sb-type spiral, resembling M-31 in stellar content. It is the primary galaxy in a cluster called the "M-81 group," which may be the nearest group of galaxies to our Local Group. About a dozen objects belong to this cluster, which lies about seven million light-years away.

Through the telescope, M-81 is a fascinating target. Use a relatively low-power eyepiece when you locate M-81, and you'll almost be certain to include M-82, which is a scant 38′ of arc north of the large spiral, in the same telescopic field. Then increase the magnification and concentrate on M-81: if you use a telescope of at least 10 inches aperture, you'll probably be able to discern part of M-81's spiral structure, and some of the dust near its nucleus and in its spiral arms. It spans 18′x10′ and shines at magnitude 8, so in a dark sky it will be a really magnificent object.

A bizarre galaxy, **M-82** is also an interesting sight in backyard telescopes. It is half as large as M-81 but only a little fainter — so under good seeing conditions, you'll still be able to see detail associated with the galaxy's strange nuclear region. If you can use a 10-incher or even a larger telescope, crank up the magnification to 25x per inch of aperture. Can you see any interstellar dust associated with M-82's thin disk?

The galaxy's disk suggests to backyard observers that it is an edge-on spiral, but professional observatory photos reveal that M-82 is a highly distorted galaxy whose structure is unexplained. A strong radio source, it seems to have undergone some sort of violent event about 1.5 million years ago. Astronomers have photographed tenuous gas being shot outward from M-82; it seems to involve about five million solar masses of material. This galaxy belongs to a class which also includes giant M-87 in Virgo, Cygnus A, and NGC-5128 in Centaurus. What could have happened to M-82? Perhaps it underwent an explosion, a collision with another galaxy, or with an enormous intergalactic dust cloud.

Another interesting galaxy in the area is **M-101**, a large face-on Sc-type spiral that presents marvelous spiral arms. M-101 is a galaxy of low surface brightness, so it doesn't show much in small telescopes — but with large reflectors it comes to life. Its ninth-magnitude light is spread over an area of 22′x20′, a size approaching that of the Full Moon. You'll need really dark skies to see this object well. Under good skies, an 8-inch scope shows it as a somewhat fuzzy blob, but a 12-incher begins to show detail in the galaxy's spiral arms. M-101 is a "lightweight" galaxy, in that it measures 90,000 light-years across



— nearly as long as the Milky Way — but holds only 10% of the Milky Way's mass. It is not at all a dense collection of material; one solar mass is thinly distributed over every 522 cubic light-years. M-101 contains an enormous number of Population I stars, so the combined light from the galaxy is very blue.

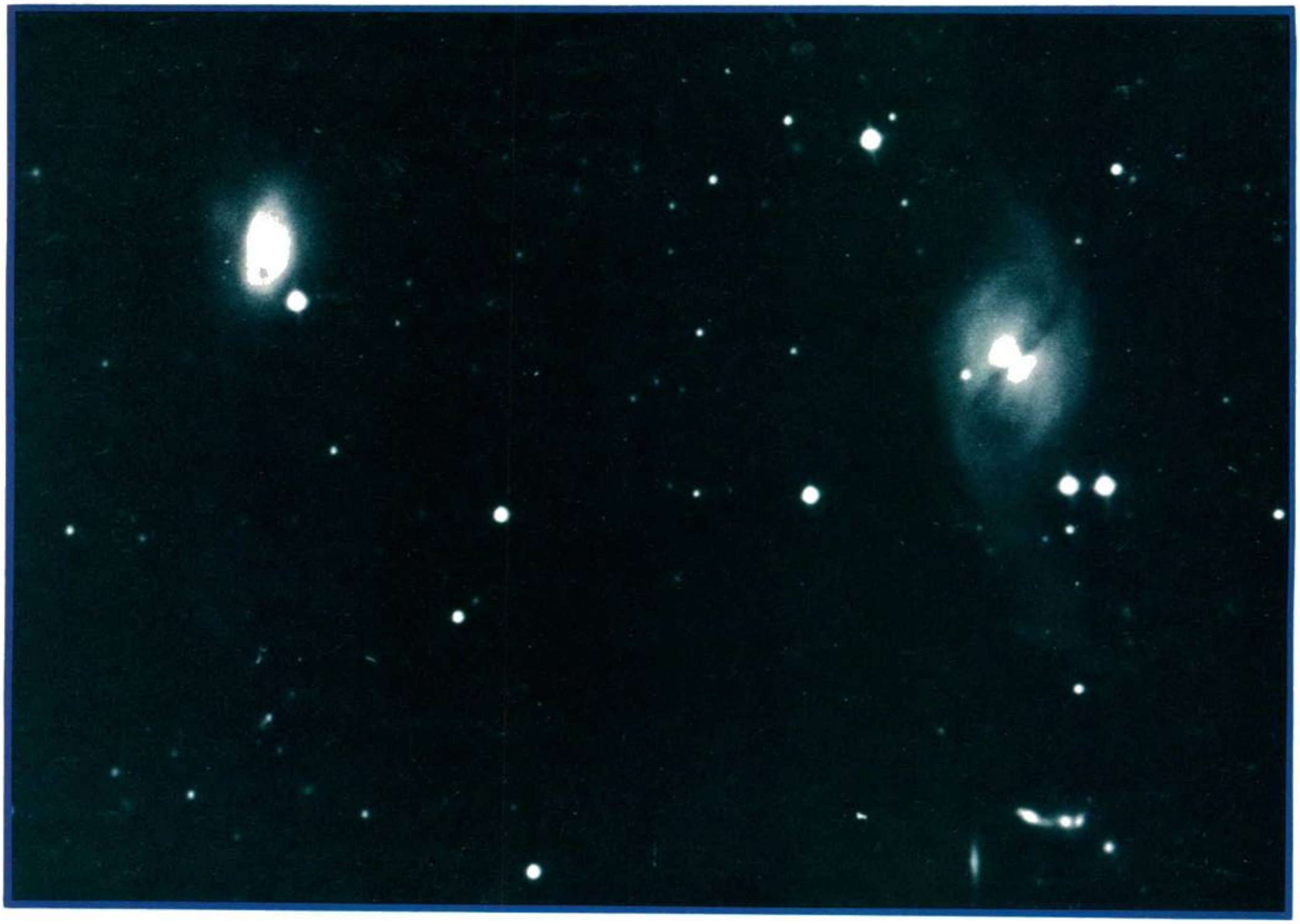
Another interesting galaxy in Ursa Major is **M-108**, an Sb galaxy whose central plane is inclined a mere 8° from our line of sight. This object is a fine sight in medium-sized telescopes, resembling a silvery needle — a fainter version of M-82. It shines at magnitude 11, measures 7.8′x1.4′, and takes magnification pretty well. If you use a big telescope and employ high magnifications on M-108, you'll be rewarded with a view of subtle dust patches along the galaxy's edge.

Just 48′ southeast of M-108 is **M-97**, the famed "Owl Nebula." This is a remarkable object: one of the four Messier planetaries, the little disk of fluorescent gas glows at magnitude 11 and is easily seen in small scopes as a hazy circle. Using considerably larger scopes, early observers saw the two dark patches — "eyes" — that led to the name *Owl Nebula*. If you observe at a top-notch site and use at least a 12-inch scope, it is possible to observe the eyes and the planetary's 14th magnitude central star.

NGC-2685 is an unusual galaxy. It seems to be lenticular, or spindle-shaped, but displays an enormous ring of matter encircling the galaxy. Astronomers don't know how to classify it or interpret exactly what is going on within it.

It isn't easy to observe NGC-2685, let alone any of its detail. The galaxy shines at magnitude 12.2, its longest axis is 3′ across, and its surface brightness is terribly low. But if you have a 16-inch or larger scope, wait until a good night and use high powers; you may be startled by the view.

Several interesting stars lie in the region. **Xi (ξ) Ursae Majoris** is a double star whose nearly equal components are pretty close — but not too close to split with small telescopes on good nights of observing. The magnitude 4.3 and 4.8 stars are separated by 2.6″ of arc. Both are a pale yellow color. This binary system is one of the closest to us — it lies only 26 light-



Two of Ursa Major's many galaxies glow softly in Alexander Brownlee's photo. NGC-3729 lies on the left, and the brighter NGC-3718 is to the right; both galaxies lie to the south of the Big Dipper's bowl. Brownlee used his 16-inch f/5 Newtonian telescope and hypered 2415 film to take the photo.

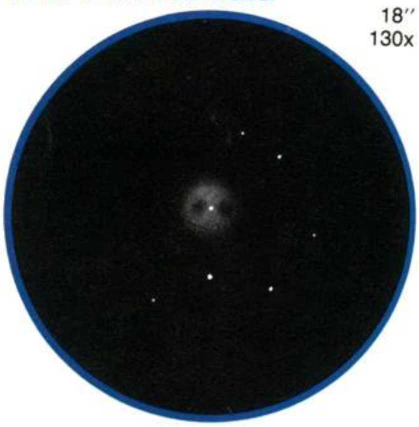
years away — and is actually a quadruple star; each star has a spectroscopic companion.

Winnecke 4 is a double star with components of magnitude 9.0 and 9.3, separated by 50.1″. Thus it is an interesting and easy pair to split, showing a fairly wide gap between the two stars. Interestingly, this rather unimportant double star was mistakenly added to the Messier list as "M-40," when Messier thought he spotted nebulosity in this area. But as a deep-sky object, M-40 is nonexistent. All that appears in this area is the double star.

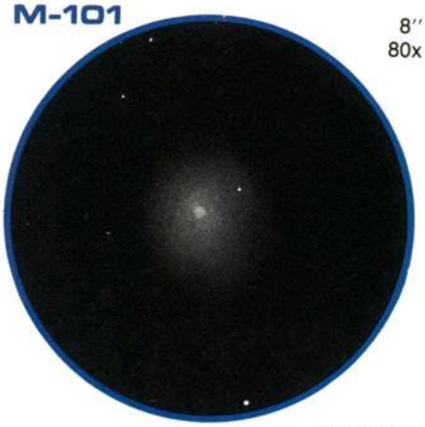
Perhaps the best-known of all double stars is **Mizar** — also known as Zeta (ζ) Ursae Majoris — which was the first double star discovered telescopically. Mizar, the middle star in the handle of the Big Dipper, forms a naked-eye double with fainter Alcor, but the two are physically unassociated. When you train your telescope (at low power) on Mizar, you'll probably see Alcor in the field of view, but bright Mizar is a close double itself! Mizar's components shine at magnitude 2.4 and 4.0, and lie 14.4″ apart. Thus the pair is easily split in most telescopes. Both stars shine with a bright white glow.

During the spring months, the Great Bear offers a huge number of galaxies — and a handful of other objects — for sky hunters who have survived the cold weather. Many types of celestial objects await you and your telescope: it's up to you to get out and make use of the good seeing, warm temperatures, and readily available galaxies.

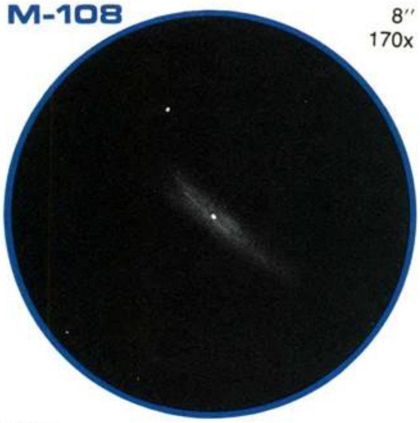
The Owl Nebula



M-101



M-108

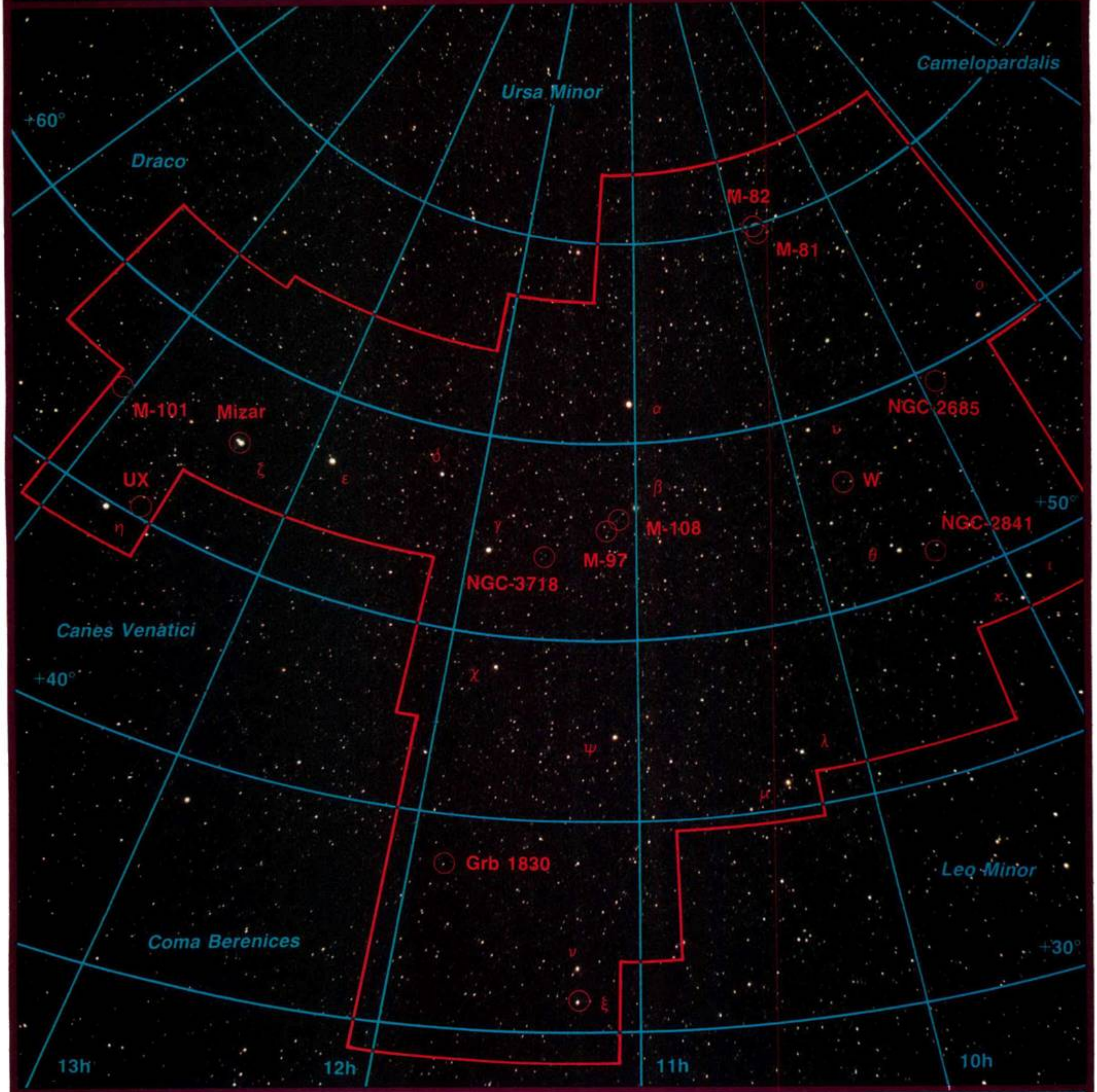


Sketches by David J. Eicher

Photo by Robert Provin and Brad Wallis

ursa major

Map by David J. Eicher


Ursa Minor
Camelopardalis
+60°
Draco
M-82
M-81
o
M-101
Mizar
α
NGC 2685
υ
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ε
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NGC-2841
M-97
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Canes Venatici
+40°
χ
ψ
λ
μ
Grb 1830
Leo Minor
Coma Berenices
+30°
ν
ξ
13h
12h
11h
10h

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (200)	Dec.
NGC-2685	§	12.2	2.5′x0.8′	08h 52m	+58°59′	08h 56m	+58°48′
NGC-2841	§	10.3	a6.2′x2.0′	09h 19m	+51°12′	09h 22m	+50°59′
W	EV	8.3-9.1	0.33d	09h 40m	+56°11′	09h 44m	+55°57′
M-81	§	8.0	18.0′x10.0′	09h 52m	+69°18′	09h 56m	+69°04′
M-82	#	9.2	8.0′x3.0′	09h 52m	+69°56′	09h 56m	+69°42′
M-108	§	10.8	7.8′x1.4′	11h 09m	+55°57′	11h 12m	+55°41′
M-97	■	11.0	150″	11h 12m	+55°18′	11h 15m	+55°02′
Xi	★²	4.3+4.8	2.6″	11h 16m	+31°49′	11h 18m	+31°33′
NGC-3718	§	11.8	3.0′x3.0′	11h 30m	+53°21′	11h 33m	+53°04′
Grb 1830	★	6.5	—	11h 50m	+38°05′	11h 53m	+37°48′
Wnc 4	★²	9.0+9.3	50.1″	12h 20m	+58°22′	12h 22m	+58°05′
Mizar (ξ)	★²	2.4+4.0	14.4″	13h 22m	+55°11′	13h 24m	+54°55′
UX	EV	12.7-13.8	0.03d	13h 37m	+52°10′	13h 39m	+51°55′
M-101	§	9.0	22.0′x20.0′	14h 01m	+54°35′	14h 03m	+54°21′

★	*Star*
★²	*Double Star*
★³	*Triple Star*
RV	*Regular Variable*
IV	*Irregular Variable*
EV	*Eclipsing Variable*
⊙	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
()	*Elliptical Galaxy*
§	*Spiral Galaxy*
∮	*Barred Spiral Galaxy*
#	*Peculiar/Irregular Galaxy*

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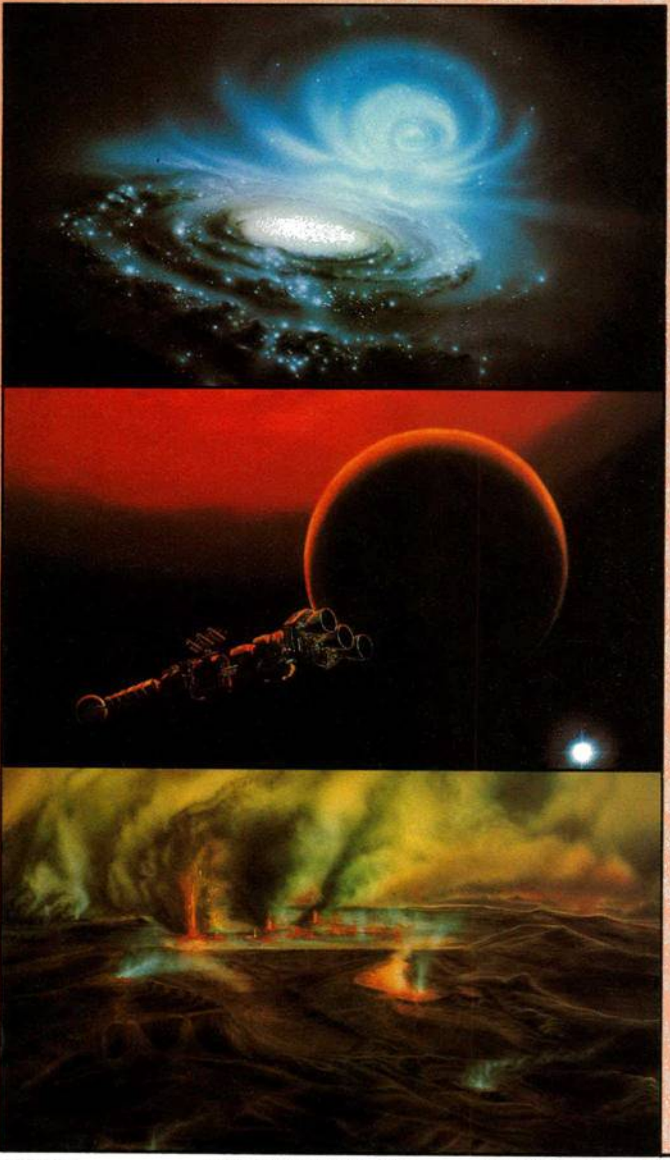

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